AD-A035 091 AEROSPACE GUIDANCE AND METROLOGY CENTER NEWARK AIR FO--ETC F/G 14/1

PROCEEDINGS OF THE LIFE CYCLE COST TASK GROUP OF THE JOINT SERV--ETC(U)

FEB 76 R B STAUFFER

UNCLASSIFIED AGMC-76-008 NL

1 OF 2

AD A035091

Life Cycle Cost Task Group

of the
Joint Services
Data Exchange
FOR INERTIAL SYSTEMS

Proceedings of Quarterly Meeting

A

24-26 February 1976
at
San Diego, California

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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Warranties
Reliability Improvement Warranties
Design-to-life-cycle-cost
Gas Turbine Engines
Failure mode effect analysis
Logistic Support Cost
Queuing Analysis

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

These proceedings describe the activities of the quarterly meeting of the Life Cycle Cost Task Group of the Joint Services Data Exchange for Inertial Systems held 24-26 February 1976. The proceedings contain texts and slides of invited papers; and reports from working groups concerned with programming, distribution, and change control of the life cycle cost model being developed by the Task Group.

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LIFE CYCLE COST TASK GROUP
OF THE
JOINT SERVICES DATA EXCHANGE FOR
INERTIAL SYSTEMS

PROCEEDINGS OF QUARTERLY MEETING

24-26 FEBRUARY 1976

AT

SAN DIEGO, CALIFORNIA

Compiled and Edited

by

Russell B. Stauffer

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PROCEEDINGS
LIFE CYCLE COST TASK GROUP
OF THE
JOINT SERVICES DATA EXCHANGE FOR INERTIAL SYSTEMS
24-26 FEB. 1976

1. INTRODUCTION

The Life Cycle Cost Task Group of the Joint Services Data Exchange for Inertial Systems met at the Catamaran Hotel, San Diego, California on 24-26 February 1976. Working sessions on Tuesday and Thursday were devoted exclusively to final revisions to the Users' Manual which accompanies the model which has been developed by the Task Group. The Papers Session, held on Wednesday, February 25, was well attended by a number of people not regularly connected with the Task Group. Section 3 of these Proceedings contains the papers which were presented to the extent they were available at the time of publication.

2. WORKING GROUP REPORTS

Kieth Gibson of Autonetics reported on his progress with programming the model and presented a revised basic flow diagram. The revisions are related principally to the order of accumulation (i.e. summarization) of costs and to the processing of the input. The former change was made to simpify programming, the latter to make it easier for the user to make sequential runs with minor data variations.

All control coding has now been completed as has the coding of all basic equations. Some intermediate equations were incomplete pending further discussion by the Task Group as a whole.

The Output Report Program was prepared by AFHRL personnel through arrangements made by Mrs. Freda Kurtz of AFAL. It was noted that some revisions to these programs will be necessary but that the programmers will be available.

Kieth reported that the model would be ready for testing during April 1976 and arrangements were made for the Master Deck to be duplicated under the direction of Mrs. Kurtz and distributed to Robert Adel (Northrop Electronics), Robert Beech (Vought Systems), William Colcord (Lear-Siegler), Don DeBurkarte (Collins Radio) and James Taylor (Honeywell) for evaluation. Distribution will be limited to these organizations until testing is complete.

Procedures for further distribution of the model were the subject of considerable discussion. All effort up to the present has been the result of voluntary contirbutions on the part of individuals and their organizations. However, it was felt that if the model should receive the desired level of use, the costs of duplication and mailing would be too burdensome for one organization to assume. Several suggestions were offered with two appearing to have merit:

1. Provide only a source deck listing and the Users' Manual through the Defense Documentation Center, requiring the user to punch his own cards.
2. Stock a central location with a small number of decks and program listings. Users would duplicate this material at their own facility and return the originals to the central location. If the central office were a military organization having "franking" privileges, costs of postage would be eliminated.

Additional suggestions from potential users would be welcome. They may be addressed to:

Russell B. Stauffer
J & R Associates
Box 58
Jackson, N.H. 03846

Some concern was also expressed over the control of changes to the model. A basic purpose in the design was to create a "standard" equally acceptable to manufacturess, the academic/research community and the Government. If organizations begin making uncontrolled changes, there will soon be numerous variants and the "standardization" will have been lost. The need for a formal "Change Control Procedure" is evident but appropriate

techniques for its implementation must still be developed.

A third area of discussion centered on the procedures to be followed in gaining acceptance of the model as a standard for inertial systems.

It is currently planned that the Summer 1976 meeting of the LCC Task Group will be devoted to a discussion of these three topics and generation of recommendations for thier implementation.

The Spring 1976 meeting will be limited in attendance to those who have participated actively in the writing of the Users' Manual and will be devoted to the final editing of that document. That meeting is scheduled for Monday, May 17 in the Dayton ,Ohio area. The specific location will be announced later.

LIFE CYCLE COST TASK GROUP

JOINT SERVICES DATA EXCHANGE FOR INERTIAL SYSTEMS

Agenda

Wednesday, Feb. 25

9:00 a.m.	Opening Remarks	R.B. Stauffer J & R Associates
9:05	Welcome	Cdr. Robert Harrison NARF, North Island
9:15	"Project Rampart - Organic Approach to RIW"	James Larkin NARF, North Island
10:00	Coffee Break	
10:15	"A Monte Carlo Risk Analysis of Life Cycle Projection"	Capt. Dwight Collins ASD/ACL
11:00	"FMEA - Design to Life Cycle Costing of Turbine Engines"	William Wagner Teledyne CAE
11:45	Lunch	
:00 p.m.	"Warranty Cotract Evaluation Risks and Questions"	Robert McGinnis Autonetics
1:45	"Cost/Time Factors in Life Cycle Cost - A Studies Report"	James Taylor Honeywell
2:30	Break	
2:45	"ASMRA Program"	John Willet REPAC

3. INVITED PAPERS

This section contains the text and slides of the presentations made on Wednesday, February 25, 1976 at the Winter meeting of the LCC Task Group of the JSDE/IS.

They are presented in the same order as they appeared on the agenda, separated by biographical sketches of the authors where they were available.

James J. Larkin NARF, North Island NAS

BSEE from M.I.T. in 1946

Mathematician at Douglas Aircraft Co. 1947-48

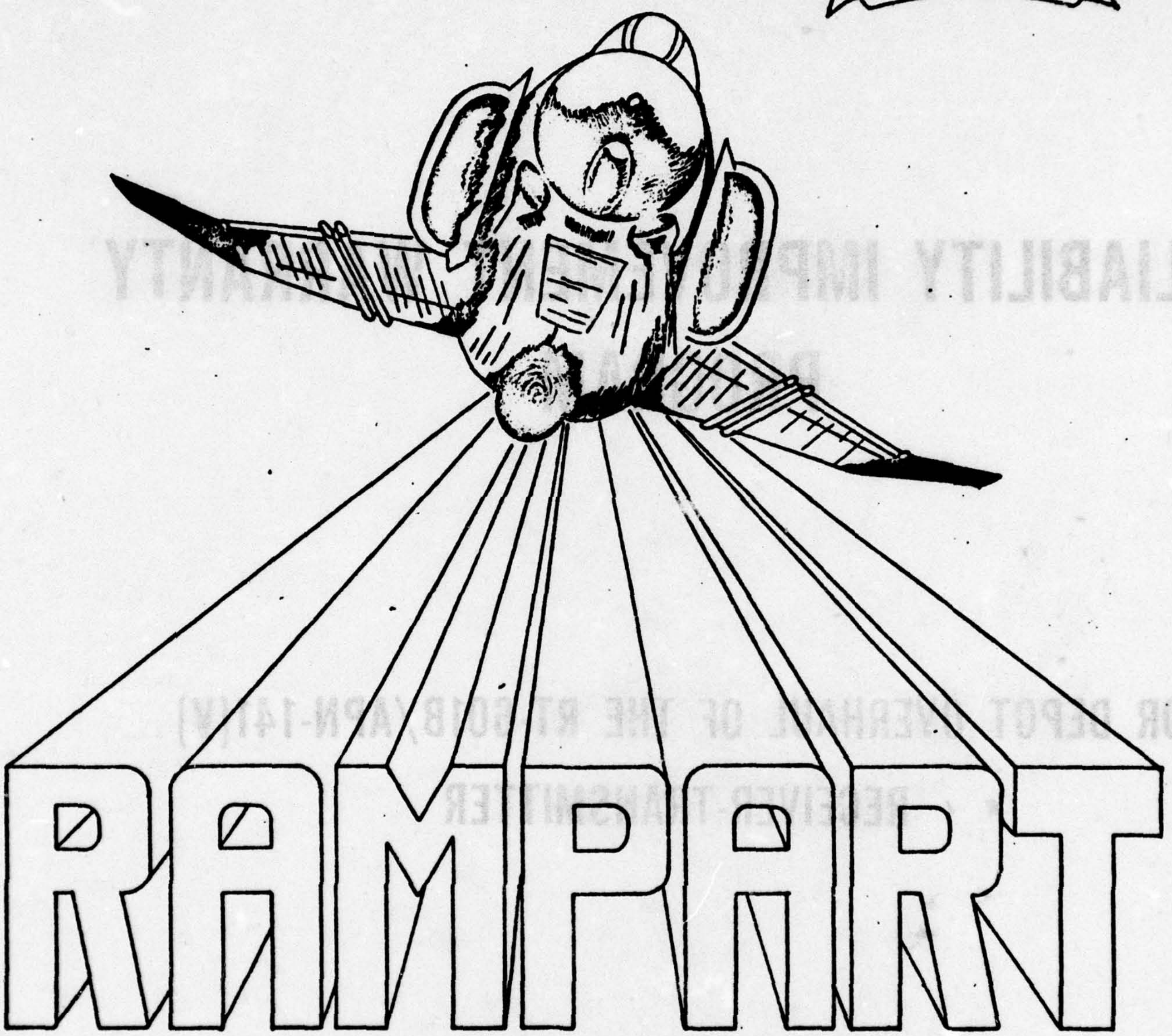
Research electircal engineer at Rand Corp. 1948-51

Recalled to active duty in the Army in 1951. Military service included project management of service tests of Nike Hercules surface-to-air missile systems at White Sands, N.M., Eglin AFB, FL and artic tests at Ft. Churchill, Canada, and a variety of other technically oriented command and staff assignments in air defense and nuclear weapons.

Retired in 1972 with grade of colonel.

Avionics and Components Division, Engineering Dept., NARF, North Island from 1973 to the present. Currently assigned Project Manager of AN/APN-141 radar altimeter Reliability Improvement Warranty (RIW) program called Project Rampart.

NAVAL AIR REWORK FACILITY



PROJECT RAMPART

Reliability Augmentation Maintenance Program, Altimeter Receiver-Transmitters

RELIABILITY IMPROVEMENT WARRANTY PROGRAM

FOR DEPOT OVERHAUL OF THE RT-601B/APN-141(V) RECEIVER-TRANSMITTER

RIW CONCEPT

- FIXED PRICE MULTI-YEAR MAINTENANCE CONTRACT
- INCENTIVE ORIENTED TO ENCOURAGE CONTRACTOR TO MAKE RELIABILITY IMPROVEMENTS IN-HOUSE (W/OUT SUPPLEMENTARY FUNDING) IN ANTICIPATION OF PAY-OFF LATER IN PROGRAM
- COST REDUCTIONS ACHIEVED BY REDUCTION IN WARRANTY RETURNS PROVIDE SOURCE OF FUNDS FOR ONGOING ENGR RELIABILITY IMPROVEMENT DESIGN EFFORT
- REDUCES OVERALL LONG TERM COST OF MAINTENANCE TO NAVY
- REQUIRES OBLIGATION OF FUNDS FOR FULL PERIOD- SHOULD BE NO LESS THAN SIX YEARS FOR TRUE RIW PROGRAM

RIW BENEFITS

- IMPROVED OPERATIONAL READINESS
- IMPROVED RELIABILITY
- REDUCED SUPPORT COSTS
- REDUCED TOTAL REPAIR COSTS

AN/APN-141 MAINTENANCE
PRESENT SITUATION

- LOW RELIABILITY
- LOW OPR READINESS
- HIGH DENSITY SYSTEM
- VERY HIGH MAINTENANCE COST
- OBSOLESCENT SYSTEM

AN/APN-141 RIW ADVANTAGES

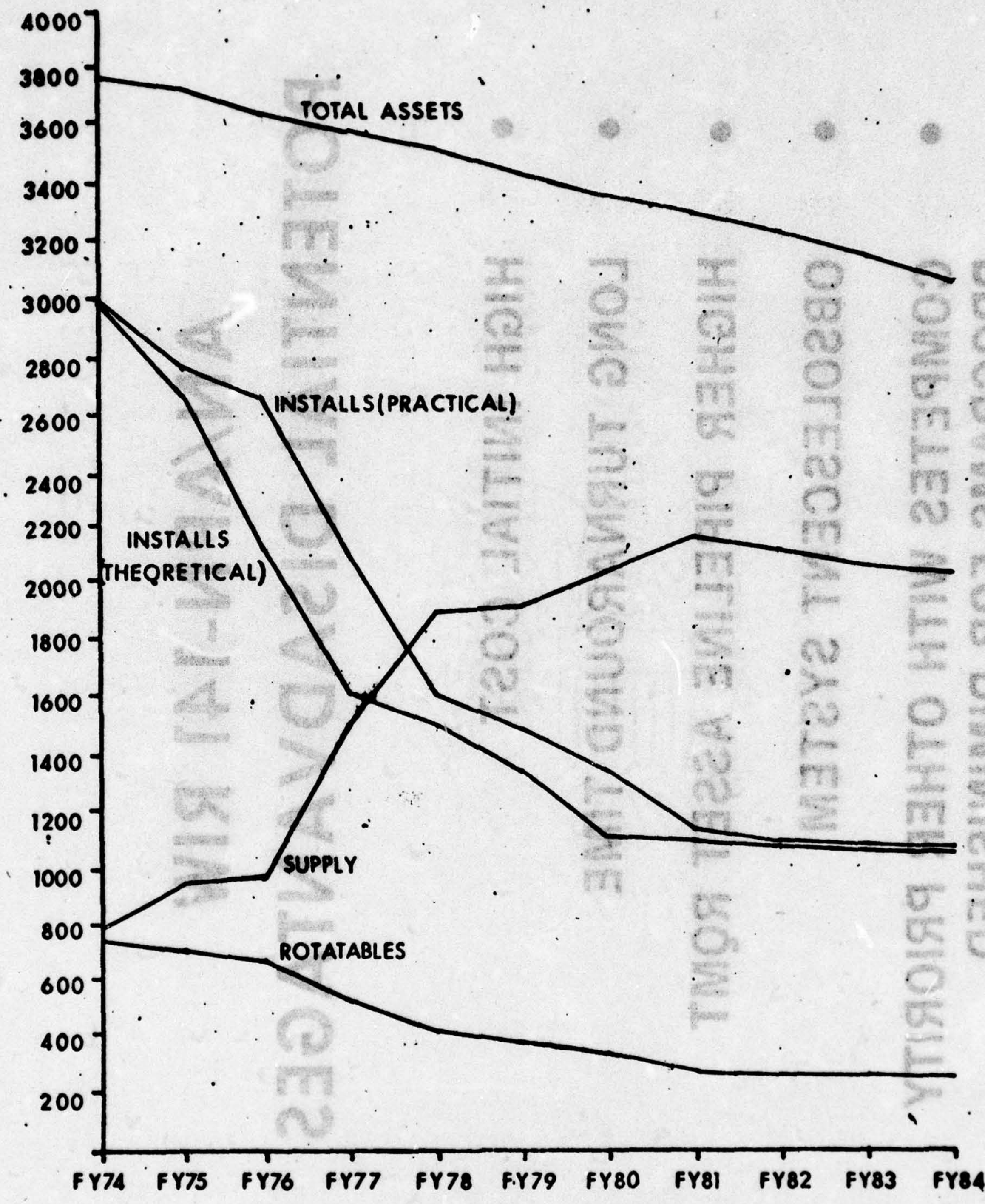
IMPROVED RELIABILITY

IMPROVED OPR READINESS

REDUCED TOTAL MAINTENANCE COSTS

AN/APN-141 RIW
POTENTIAL DISADVANTAGES

- HIGH INITIAL COST
- LONG TURNAROUND TIME
- HIGHER PIPELINE ASSET RQMT
- OBSOLESCENT SYSTEM
- COMPETES WITH OTHER PRIORITY PROGRAMS FOR DIMINISHED RESOURCES



CURRENT AND PROJECTED AN/APN-141 RT POPULATION

RELIABILITY IMPROVEMENT MEASURES

COST-EFFECTIVE DESIGN CHANGES

MINOR CIRCUIT CHANGES
IMPROVED WAFERS
(STATE-OR-THE-ART COMPONENTS)
IMPROVED REACTORS
REPLACEMENT OF LEAKING ELECTROLYTIC CAPACITORS
IMPROVED INSULATION IN XMTR CAVITIES

IMPROVED REWORK PROCEDURES

UPGRADED SKILL LEVEL TO BE REQD

ACCOUNTABILITY FOR QUALITY BY NAME

MORE STRINGENT QUALITY CHECK LIST (QCL)

BURN-IN TO REDUCE INFANT MORTALITY

CENTRALIZED PROJECT MANAGEMENT

MAINTENANCE CONCEPT CHANGE

WHOLESALE REPLACEMENT OF MODULES

CAVITY INSTALLATION SHORT CIRCUITS

CAVITY FILAMENT OVER-VOLTAGE

SUPPLY LEADTIME-AWP PROBLEM

TRAINING PROBLEM

OTHER AIMD INDUCED FAILURES

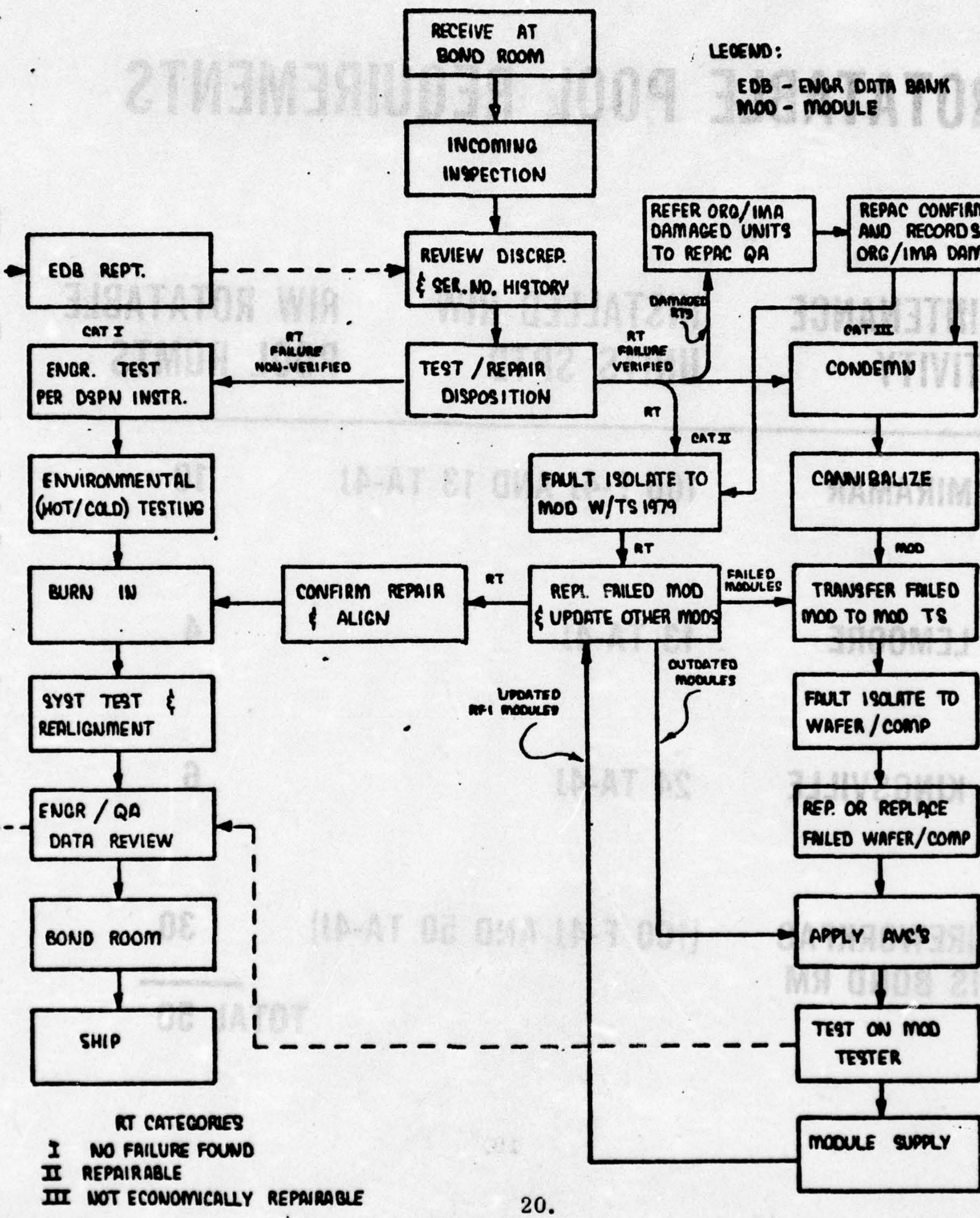
AIRCRAFT RIW INSTALLATIONS

TYPE	NO.	FH/AIRCRAFT/YR	EST. TOTAL FH/YR
F-4J/N	100	243	24,300
TA-4J	50	417	20,850
TOTALS	150		45,150

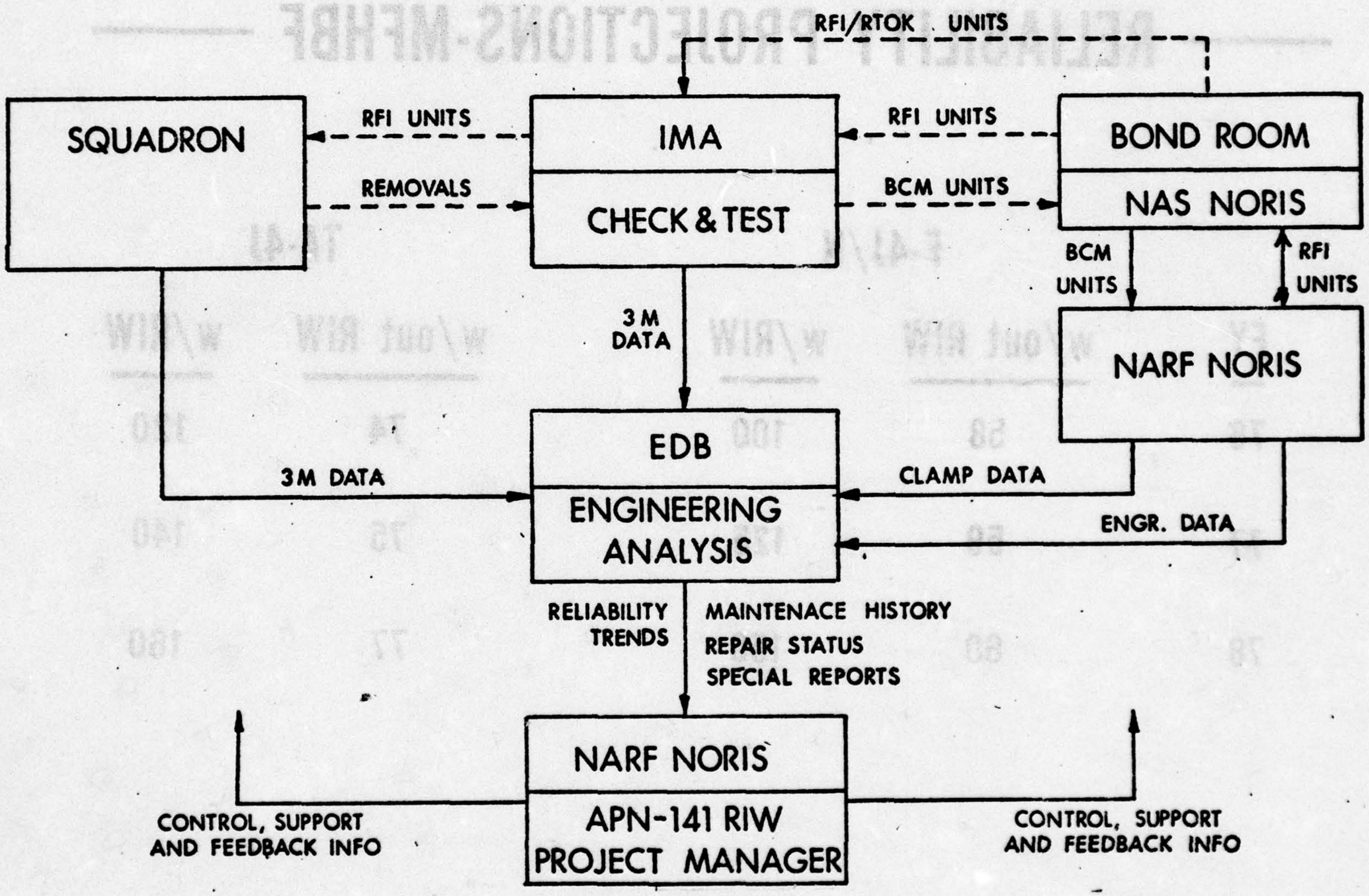
ROTATABLE POOL REQUIREMENTS

MAINTENANCE ACTIVITY	INSTALLED RIW UNITS SPTD	RIW ROTATABLE POOL RQMTS
AIMD MIRAMAR	100 F-4J AND 13 TA-4J	10
AIMD LEMOORE	13 TA-4J	4
AIMD KINGSVILLE	24 TA-4J	6
NAVAIREWORKFAC NORIS BOND RM	(100 F-4J AND 50 TA-4J)	30
		TOTAL 50

RIW FLOW CHART FOR REWORK

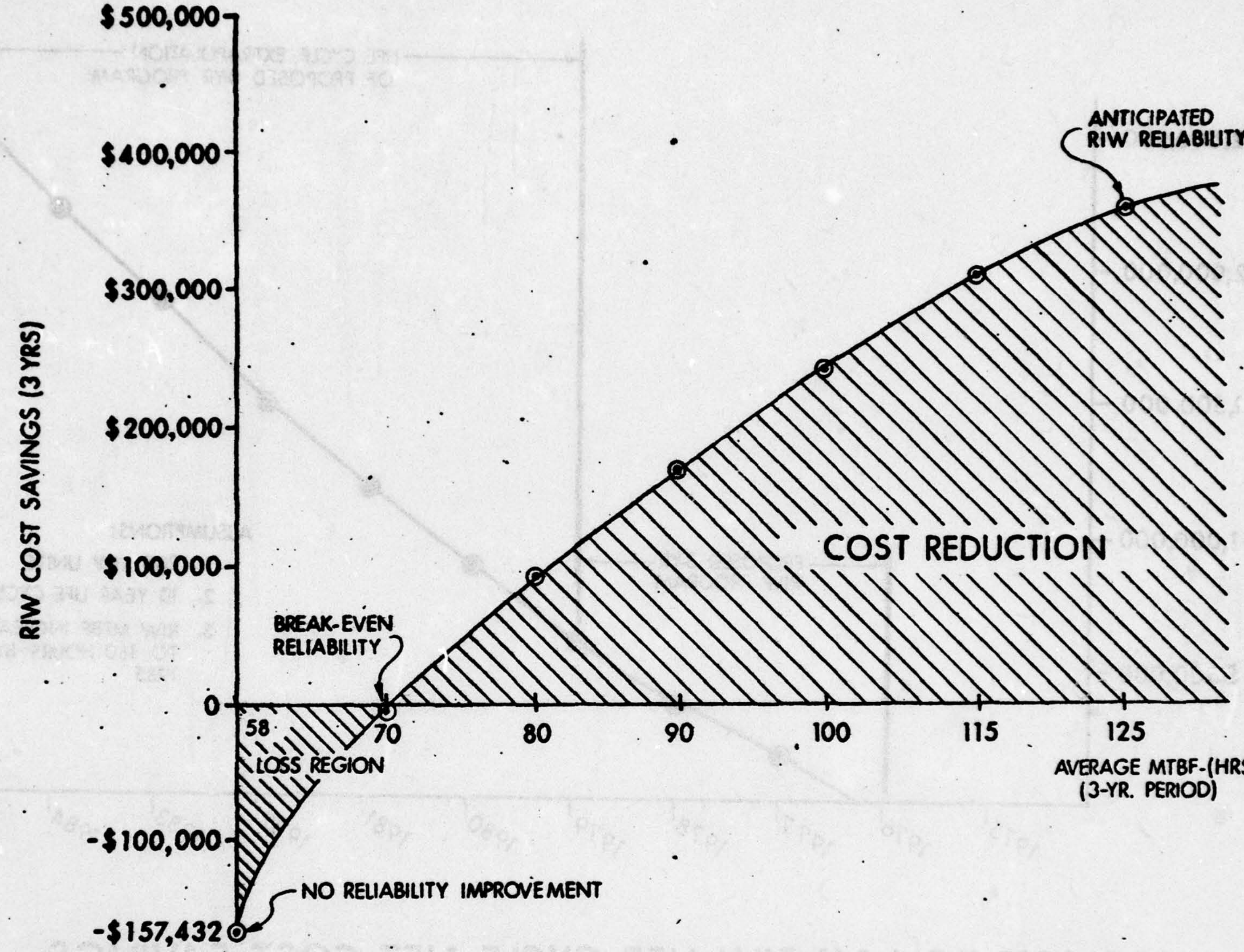


RIW PROGRAM INFORMATION FLOW

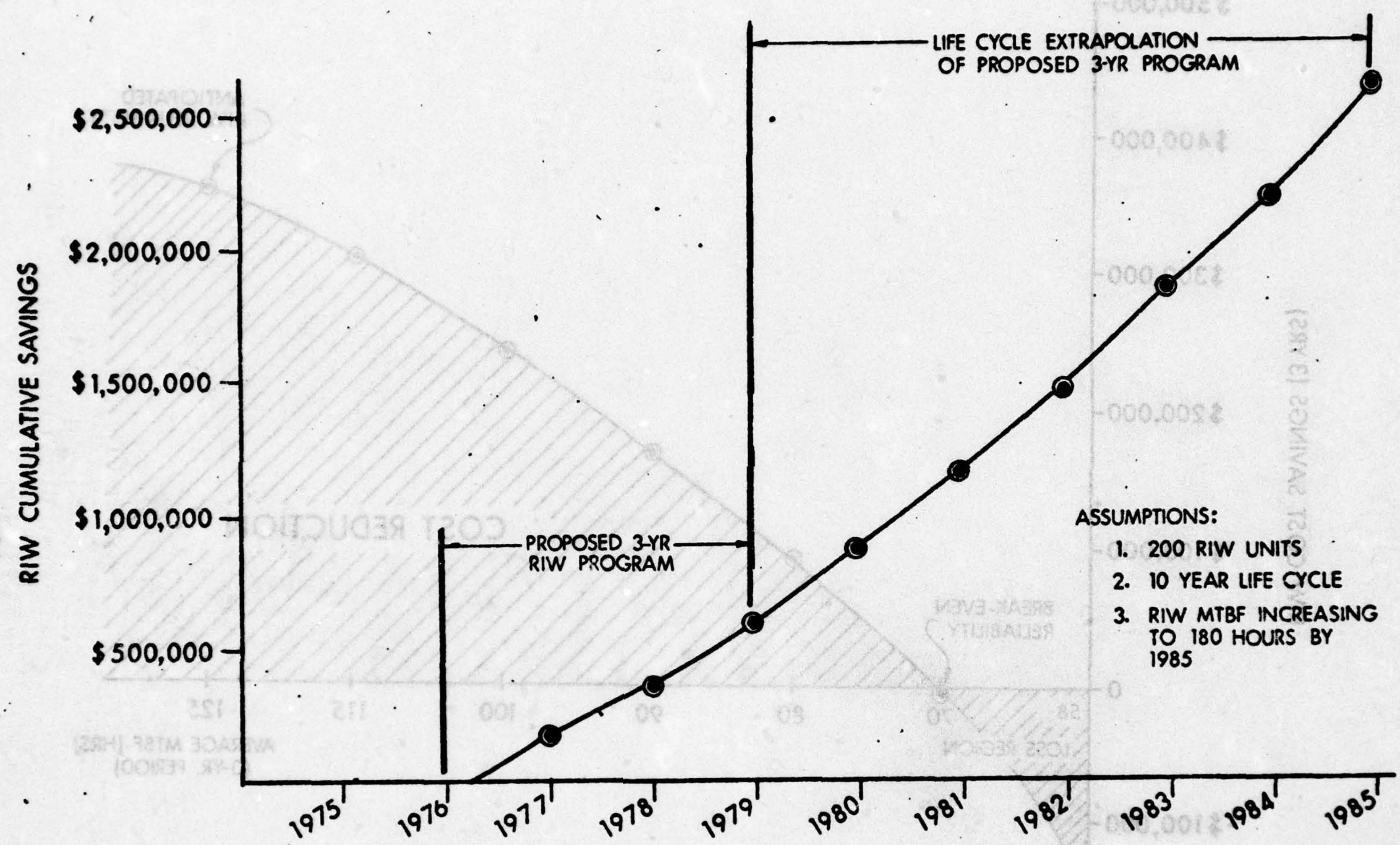


RELIABILITY PROJECTIONS-MFHBF

	F-4J/N		TA-4J	
FY	w/out RIW	w/RIW	w/out RIW	w/RIW
76	58	100	74	120
77	59	125	75	140
78	60	150	77	160



RIW COST SAVINGS VS RELIABILITY



RT-601B/APN-141 RIW LIFE CYCLE NET COST SAVINGS

Captain Dwight E. Collins is a member of the Joint AFSC/AFLC Working Group on Life Cycle Cost and has been active in couseling students at the Air Force Institute of Technology.

He hold a Ph. D. in Operations Research from Cornell University.

<u>A Monte Carlo Risk Analysis</u>
<u>of Life Cycle Cost Prediction</u>

by
Capt Dwight E. Collins
Joint AFSC/AFLC Commanders' Working Group
on Life Cycle Cost

In recent years, several Air Force procurements have made use of a contractual commitment with respect to supportability as a means of reducing equipment life cycle costs. Such a commitment is typically called a logistic support cost commitment. It usually involves (1) the development of a target logistic support cost which is incorporated in the production contract and (2) the structuring of a field test procedure by which a representative sample of field logistic support costs is collected and compared to the target. It may also include instructions for exercising award fee provisions or correction of deficiency provisions as a function of whether the sample of field logistic support costs underruns or overruns the target.

Capt Collins reported on a Masters thesis recently completed in the Air Force Institute of Technology School of Engineering that analyzed the statistical risks inherent in the logistic support cost commitment.* The thesis examines the logistic support cost commitment in the production contract for the F-16 aircraft and uses a simulation procedure to estimate the statistical risks to the government and the contractor that are reflected in this provision. It also discusses the sources of risk and examines the impact of varying field test length on risk.

Capt Collins is doing further research in this area and documentation of his results will be available by July 1976.

Copies of most of the briefing charts used by Capt Collins appear below.

---

* "A Monte Carlo Risk Analysis of Life Cycle Cost Prediction," Capt Samuel B. Graves, Department of Systems Management (AFIT/ENS), School of Engineering, Air Force Institute of Technology, Wright-Patterson AFB, Ohio 45433. Further inquiries about this thesis should be directed to AFIT/ENS (513/255-5758).

CURRENT USES OF LCC

- POINT ESTIMATE OF LCC AS EVALUATION CRITERION
  - DSARC REVIEW PROCESS
  - SOURCE SELECTION PROCESS
- POINT ESTIMATE OF LCC AS TARGET FOR CONTRACTUAL COMMITMENT WITH RESPECT TO SUPPORTABILITY
  - VERIFICATION TEST IN THE FIELD

F-16 CONTROL FLUs

DEFINITION - SET OF HIGH LSC FLUs FOR WHICH THERE EXISTS A TLSC AND A POTENTIAL POSITIVE OR NEGATIVE INCENTIVE AS A RESULT OF VALUE OF MLSC RELATIVE TO TLSC

LIST - HEADS UP DISPLAY
NAVIGATION UNIT
FIRE CONTROL COMPUTER
ELECTRONICS FOR HUD
FLIGHT CONTROL COMPUTER
RADAR EO DISPLAY
DIGITAL SCAN CONVERTER
ELECTRONICS EO DISPLAY
RECEIVER EXCITER
DATA PROCESSOR
SIGNAL PROCESSOR
TRANSMITTER
ANTENNA

LOGISTIC SUPPORT COST FOR F-16 CONTROL FLUs

C_1 = COST OF FLU SPARES

C_2 = COST OF ON-EQUIPMENT MAINTENANCE

C_3 = COST OF OFF-EQUIPMENT MAINTENANCE

TARGET LOGISTIC SUPPORT COST

$$= TLSC = \sum_{i=1}^{13} (C_{1i} + C_{2i} + C_{3i})$$

= A NUMBER ($38M) CURRENTLY IN F-16 CONTRACT

MEASURED LOGISTIC SUPPORT COST

$$= MLSC = \sum_{i=1}^{13} (\tilde{C}_{1i} + \tilde{C}_{2i} + \tilde{C}_{3i})$$

= A POINT ESTIMATE OF REAL 15 YEAR LOGISTIC SUPPORT COSTS REPRESENTED BY C_1, C_2, AND C_3

SIMPLIFIED LOGISTICS SUPPORT COST MODEL

$$C_1 = \sum_{i=1}^{n} \left[(STK_i)(M)(UC_i) + (PFFH)(UF_i)(QPA_i)(1-RIP_i)(NRTS_i)(DRCT_i)(UC_i) \;/\; (MTBF_i)\right]$$
$$+ \sum_{i=1}^{n} (TFFH)(UF_i)(QPA_i)(1-RIP_i)(COND_i)(UC_i) \;/\; (MTBF_i)$$

WHERE STK_i IS THE MINIMUM SUCH THAT

$$\sum_{X > STK_i} (X - STK_i)\; P\,(X \mid \lambda T) \leq EBO,$$

$P\,(X \mid \lambda T)$ IS POISSON, AND

$$\lambda T = (PFFH)(UF_i)(QPA_i)(1-RIP_i)\; \left[(RTS_i)(BRCT_i) + (NRTS_i)\; X\; (OSTCON\,(1-OS) + (OSTOS)(OS))\right] \;/\; (M)(MTBF_i)$$

$$C_2 = \sum_{i=1}^{n} (TFFH)(QPA_i)(UF_i)(PAMH_i + (RIP_i)(IMH_i) + (1-RIP_i)(RMH_i))(BLR) \;/\; (MTBF_i)$$
$$+ (TFFH)(SMH)(BLR) \;/\; (SMI)$$

$$C_3 = \sum_{i=1}^{n} (TFFH)(QPA_i)(UF_i)(1-RIP_i)\; \left[(RTS_i)(BMH_i)(BLR + BMR) + (NRTS_i)(DMH_i)(DLR + DMR)\right] \;/\; (MTBF_i)$$

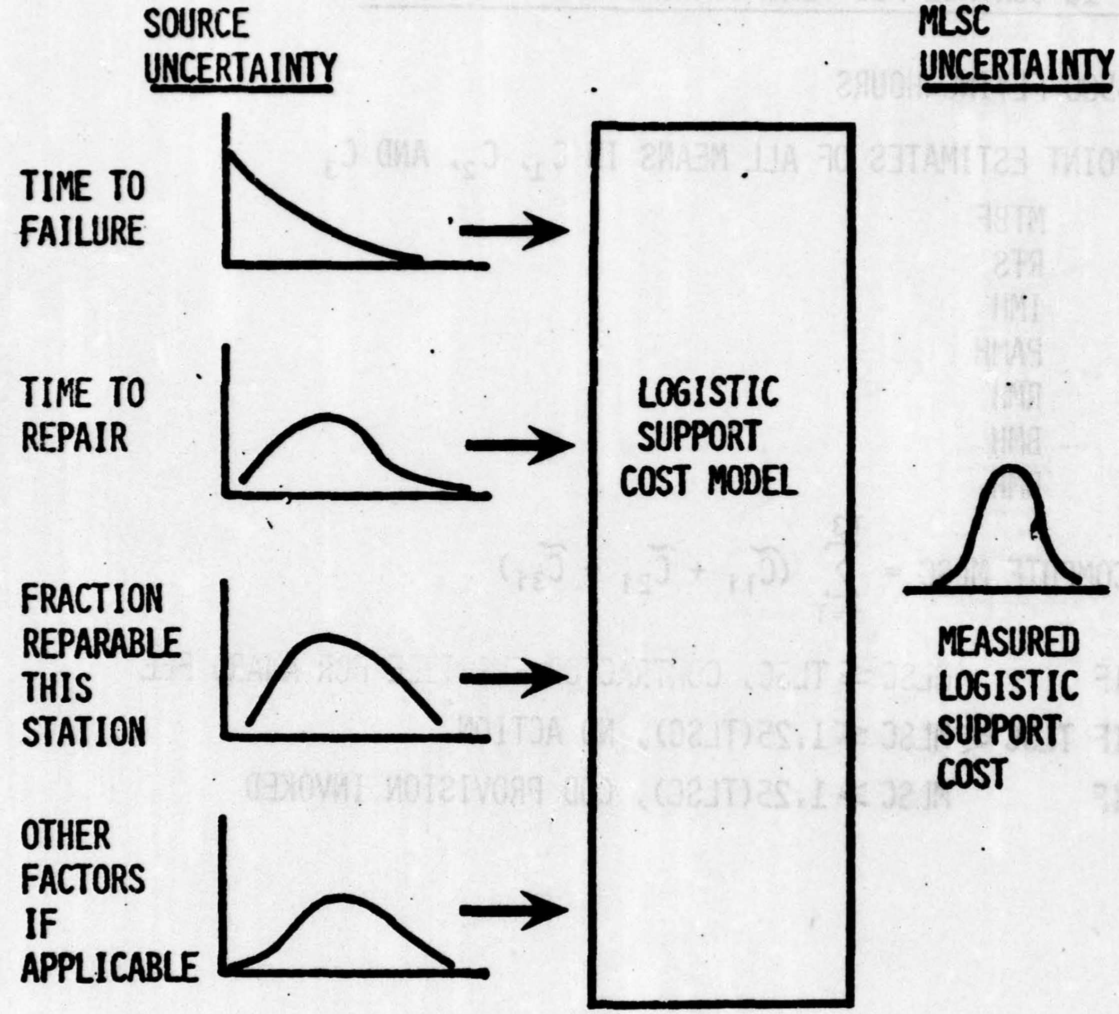
F-16 CONTROL FLU VERIFICATION TEST PROCEDURE

- 3500 FLYING HOURS
- POINT ESTIMATES OF ALL MEANS IN C_1, C_2, AND C_3
  - MTBF
  - RTS
  - IMH
  - PAMH
  - RMH
  - BMH
  - DMH
- COMPUTE $MLSC = \sum_{i=1}^{13} (\tilde{C}_{1i} + \tilde{C}_{2i} + \tilde{C}_{3i})$
- IF $MLSC \leq TLSC$, CONTRACTOR ELIGIBLE FOR AWARD FEE

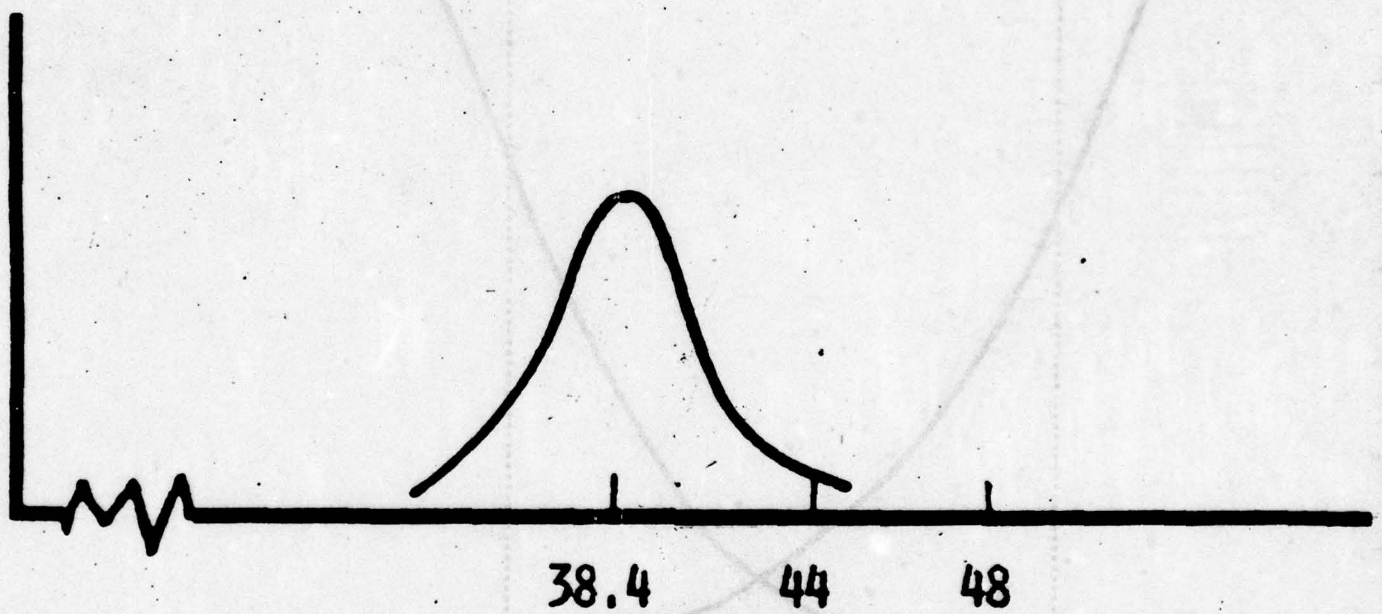
  IF $TLSC < MLSC \leq 1.25(TLSC)$, NO ACTION

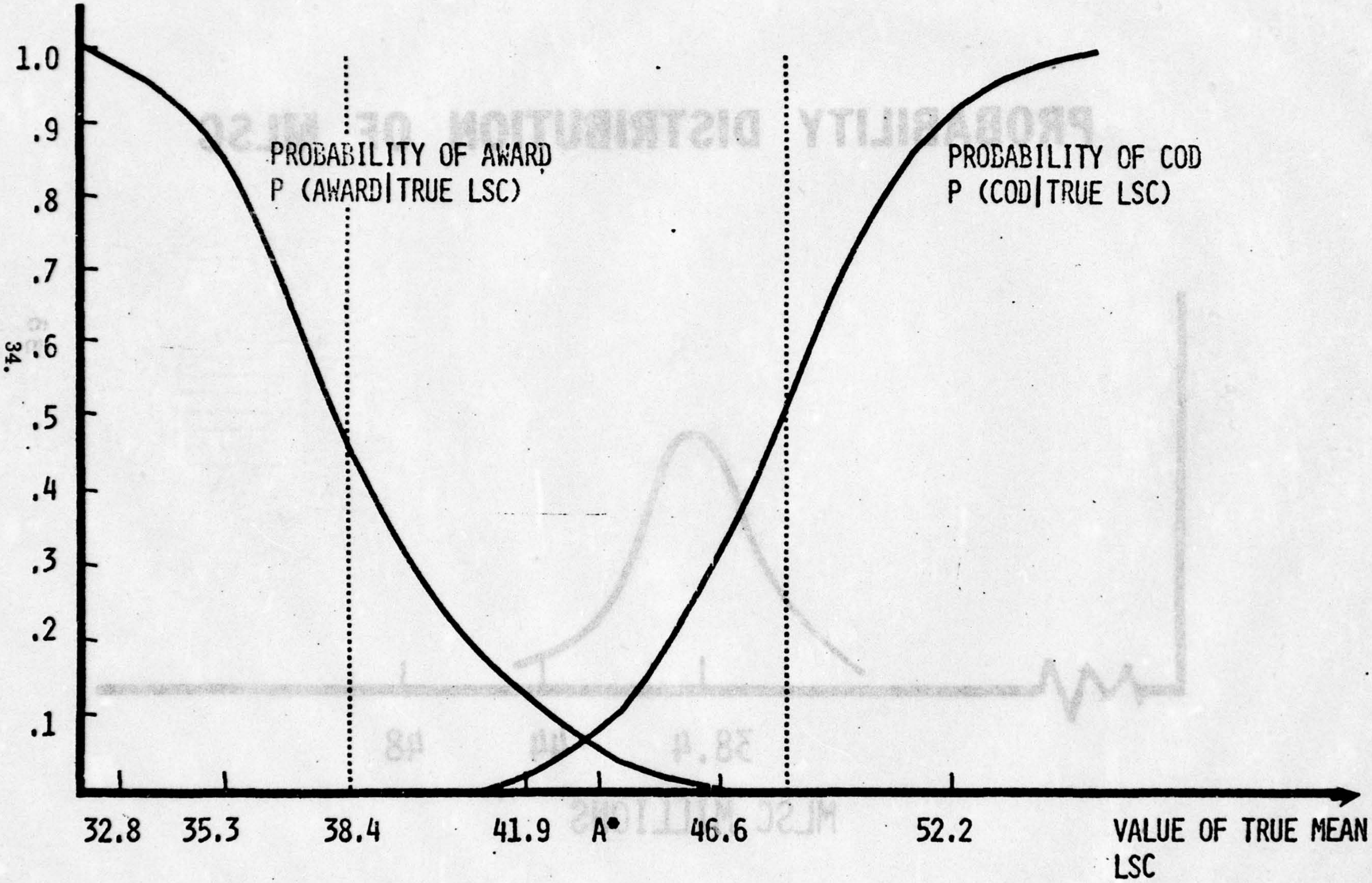
  IF $MLSC > 1.25(TLSC)$, COD PROVISION INVOKED

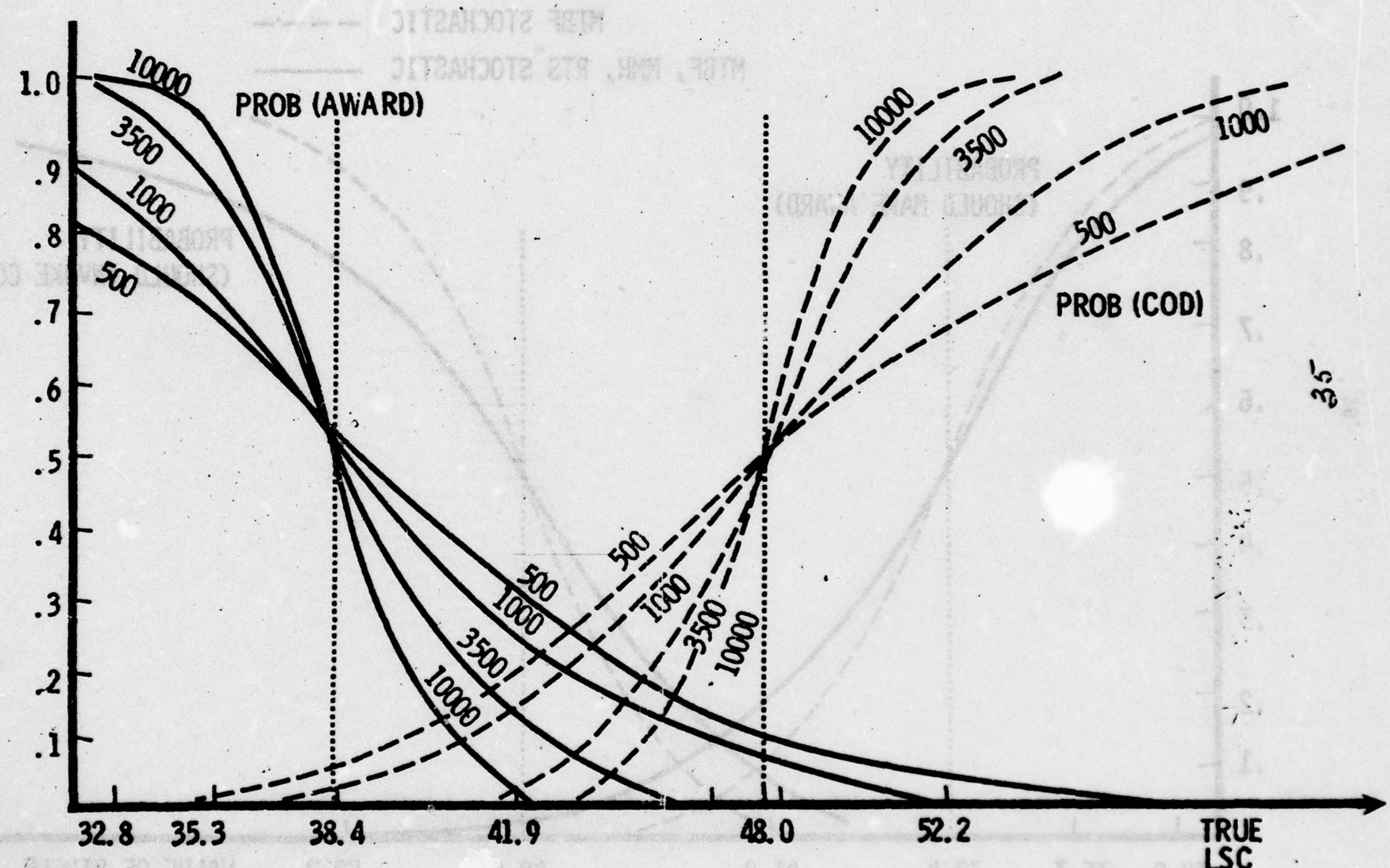
UNCERTAINTY SOURCES

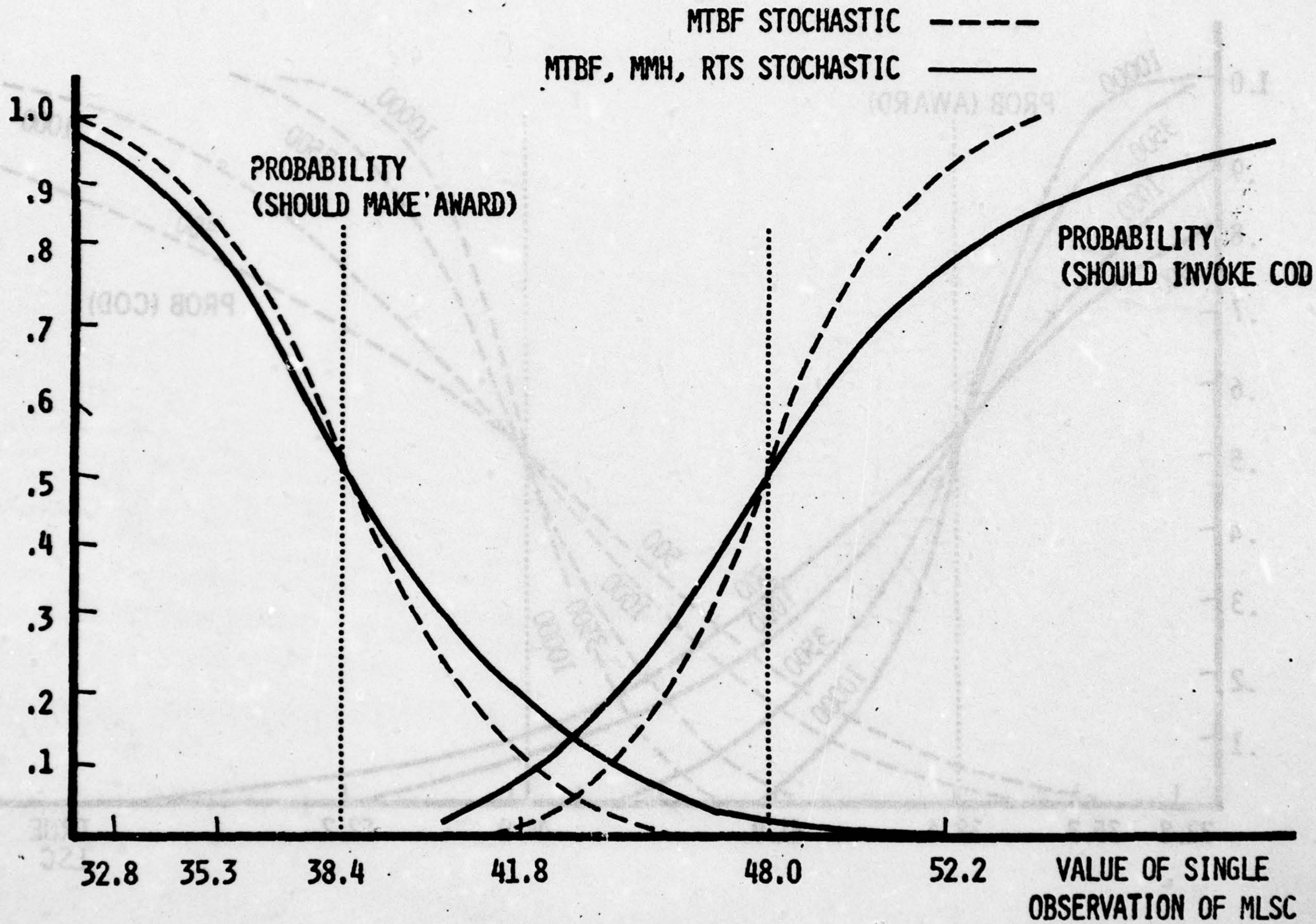


PROBABILITY DISTRIBUTION OF MLSC




PROBABILITY OF AWARD
P (AWARD|TRUE LSC)
PROBABILITY OF COD
P (COD|TRUE LSC)
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
32.8
35.3
38.4
41.9
A*
46.6
52.2
VALUE OF TRUE MEAN LSC


PROB (AWARD)
PROB (COD)
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
32.8
35.3
38.4
41.9
48.0
52.2
TRUE LSC
10000
3500
1000
500


MTBF STOCHASTIC
MTBF, MMH, RTS STOCHASTIC
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
PROBABILITY
(SHOULD MAKE AWARD)
PROBABILITY
(SHOULD INVOKE COD
32.8
35.3
38.4
41.8
48.0
52.2
VALUE OF SINGLE
OBSERVATION OF MLSC

Bill Wagner is Design Assurance Manager at Teledyne CAE directing engineering effort for reliability and other system disciplines.

He was nineteen years in the aircraft equipment industries with companiessuch as Teledyne, Fairchild, Grumman, Sperry and Arinc Research.

He is a member of the ASQC, IEEE and SAE. His B.S. was earned at Adelphi U. He is a registered professional engineer in California.

Report No. 1473

FAILURE MODE EFFECT ANALYSIS IN DESIGN TO LIFE CYCLE COST OF GAS TURBINE ENGINES

By: William Q. Wagner
Teledyne CAE
Toledo, Ohio

Office of the Secretary of Defense (OSD)
Seminar on Engine Design and Life Cycle Cost
Naval Air Development Center
Warminster, Pennsylvania
November 19-20, 1975

OUTLINE

Teledyne CAE
Report No. 1473

"FMEA IN DESIGN-TO-LCC OF GAS TURBINE ENGINES"

William Q. Wagner
Manager, Design Assurance
Teledyne CAE
Toledo, Ohio

ABSTRACT

This paper presents an approach to a most difficult yet potentially rewarding task in life cycle cost analysis of gas turbine engines: identifying the maintenance cost consequences of design decisions. The technique involves the use of a failure mode effect analysis (FMEA), with consequences extended to consideration of non-fault initiated events including scheduled maintenance.

The FMEA is in widespread use and this paper orients it to the example of a small flying gas turbine engine - in a utility/trainer application. Also, since useful analysis of maintenance cost is not likely to be successful in "free-space" this paper reviews a system level LCC analysis technique - of which the FMEA is a necessary subroutine.

Costs of engine ownership are also sensitive to the aircraft's mission and engine mounting provisions - so these details are postulated for a typical application. The end objective of engine LCC analysis lies in identifying the cost consequences of an engine design (be they maintenance or other); challenging these costs with design controllable iterations; and thereby reducing them to a customer recognized optimum. To that end some examples of prospective maintenance-cost-impacting design changes are furnished.

INTRODUCTION

The Department of Defense has clearly announced its intention to consider the comparative life cycle costs (LCC) of candidate equipments for defense procurement. DOD Directive 5000.28(1) establishes policy and guidance for across-the-board use in systems acquisition. The invitation to this seminar confirms that the gas turbine propulsion engine will be included in the list of LCC-considered items.

DOD is perhaps the major buyer of gas turbine engines and is certainly the major sponsor of advances in their technology. So, as engine developers and producers, it behooves us to: acknowledge the trend to increasing rigor in our customers' LCC analysis; acquire understanding of his cost-of-engine-ownership problem; and respond with engine designs having advantageous benefit-cost ratios.

INTRODUCTION (Cont'd)

In that regard, two realities of the gas turbine propulsion engine's development and acquisition cycle are worth citing because they should impact the engine manufacturers' approach to LCC.

The first concerns the relationship of cost to other design parameters, including performance, weight, reliability, and serviceability. Heretofore, these tended to be separately addressed and evaluated in the engine design process. Thrust, thrust to weight, and SFC were of interest to the performance specialists of the buyer and seller; while reliability, cost, and logistics aspects were often treated in separate and unrelated evaluations.

However, Reference [2] makes a good point that:

> "One of the interfaces at which these approaches often converge is their common involvement with the logistic support of operating systems, the costing of which through LCC forces these programs into a balanced relationship."

A second reality of life in engine development, shown in Figure 1, is the time in an engine's life cycle at which it comes under the buyer's cost-benefit scrutiny. One source [3] suggests that DOD and its agencies will evaluate the LCC advantages of competing engines after eighty-five percent of their design is frozen. Moreover, a DOD-accomplished LCC analysis will not employ (or have available) the time and resources necessary to iterate designs of competing engines for cost-benefit optimizing purposes.

The following import of these realities is offered:

(1) Engine designers and developers should acquire and use techniques for cost-optimizing engine designs that address the full spectrum of ownership costs.

(2) Prospective engine designs should be evaluated and designed for their cost benefit advantages well before they are committed to the buyer's final selection process.

LCC IN THE ENGINE DESIGN PROCESS

The elements and available data for an engine LCC analysis depend of necessity, on its location within the sequence of other events and opportunities for analysis in the engine design process. It is not likely to be done usefully in "free-space", because too many of the necessary inputs are not available. Such inputs as the number and duration of aircraft missions, the number and cost of engine components (especially spare-part-candidates) and the consequences of part failure are (as discussed later) absolutely necessary items of input data. In fact, Sills in his broad treatment of propulsion engine/tradeoffs [4] concludes with justification that tradeoff factors are best applied when an engine concept reaches the point where the engine designer, the manufacturer of its prospective aircraft and the owner/operator can collaborate in the tradeoff process.* On the other hand, there is an engine community consensus that says in effect: once an engine's mechanical design is committed to development phase hardware - the best chance to influence that design has been bypassed.

The suggested time bounds for effecting engine LCC optimization then are:

(1) Initiate evaluation and tradeoff as soon as a prospective aircraft, operator and mission are identified.

(2) Complete the major LCC effort and engine design optimization before the first chips are cut.

After development is underway, analysis can and should continue in order to converge a soundly derived baseline engine design.

AN ENGINE LCC METHODOLOGY

Given that an LCC analysis is not useful in free space, it is reasonable to conclude that an (extended consequence) FMEA is also not useful unless it supplies a necessary role in a fully scoped analysis. To use an electronics industry analogy, the FMEA is a "black-box" that receives inputs, and converts them to system compatible outputs. Hence, in order to understand its role, we first need to consider the system and mission that it serves, and the unique requirements of engine LCC models.

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*This is often effected by executing study phase sub-contracts of nominal cost, in which either an engine or an airframe contractor may be "prime".

AN ENGINE LCC METHODOLOGY (Cont'd)

Teledyne CAE is charged, under the requirements of advanced development contracts, to develop and/or employ design to life cost methodology for propulsion engines*. We, therefore, reviewed existing LCC models including those described in (5) and (6) together with recent experience described in Figure 2, and concluded that each had one or more of the following disadvantages, as summarized in Figure 3.

- Existing models are generally electronic-system oriented and are best applied to a system of independently removable modules (e.g., circuit boards, trays or drawers) whereas engine maintenance is a sequential process.
- The models assume that the equipment's operating environment is steady-state as opposed to the dynamic operating and stress environment of gas turbine engines.
- The important cost elements of engine/aircraft interaction and risk-weighted cost-benefits are not addressed.

In summary, an off-the-shelf model for engine use was not available, while the work of adapting existing models to conduct frequent, timely, and credible evaluations was found to be less cost effective than the development of an engine-oriented model.

An engine-oriented Design-To-Life-Cost Model is now in progress, and thus far its use does not portend any radical change in the basic process of engine design evaluation.** That is; first an initial performance parameter set will establish the aerodynamic/thermodynamic approach. A mechanical design will then be required to respond to the aero/thermo demand. Finally, a "cost-effectiveness" critique of the mechanical design should challenge, or establish a justification for the existence of cost-significant design features. The critique must of course feed back to the initial performance-requirement assumptions. In other words, a viable baseline engine design remains the first requirement for conducting a practical evaluation.

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*The need for this approach was recognized and work initiated under the USAF/APL sponsored Aircraft Propulsion Subsystem Integration (APSI) Program. Its development continues under the USAF/USN sponsored Joint Technology Demonstrator Engine (JTDE) Program.

**Most proponents of LCC agree that the approach does not require much additional data. Its prime benefit lies in bringing many known and some estimated details into an integrated and systematically ordered evaluation.

AN ENGINE LCC METHODOLOGY (Cont'd)

The modeling approach developing at Teledyne CAE defers to the foregoing axiom, as illustrated in Figure 4 and described below.

1. Mission Description - A number of mission profiles or a composite mission are described so that match points can be identified in the engine performance deck.

2. Engine/Aircraft Description - The engine and its candidate air vehicles are described in an "input document". The engine parameters listed include weight, performance, and component complement (Work Unit Code structure). The aircraft parameters include weight, development/acquisition cost, number of engines, and fuel capacity.

3. Inventory Function - An inventory model is prepared to calculate engine deliveries, annual engine flying hours, and mission frequency during the build-up, steady-state and phase-out years of engine life.

4. Functional Relationships - A number of functional relationships are identified and entered. These include:

   a) Engine ownership cost estimating relationships (CER's), component reliability distributions (for significant components) based on thermal/mechanical stresses at discrete mission conditions (match points).

   b) Aircraft development and acquisition cost sensitivity to engine weight and performance variations.

5. Design-to-Cost (DTC) Analysis - Acquisition cost values are entered for significant components (particularly those that will be replaced during maintenance). Cost values for engine assembly, inspection and testing are separately identified, as is the acquisition cost of the complete engine.

6. Development Costs - are determined for the baseline engine and proposed development program. During iterations, the development objectives are treated probabilistically to address technical risk versus payoff.

7. Acquisition Costs - are calculated for each period in which engines and spares will be purchased.

AN ENGINE LCC METHODOLOGY (Cont'd)

8. Initialization Costs - are determined as a function of the proposed stocking policy and the number of parts added to DOD inventory.

9. Operating Costs - are estimated in two categories as follows:

a) Operation and Support Costs are based on reliability, maintainability and replacement parts cost (using the FMEA with extended consequences).

b) Interactive Costs are based on the estimated cost of the baseline aircraft and the calculated effect of engine changes using the aircraft CER's.

10. Reporting Generation, Baseline - a systems cost estimate is prepared (manually or by executing a computer program) to identify costs of the baseline design during the program life cycle. Calculated parameters will include:

- Total system costs and the year in which the cost is incurred.
- Cost breakout to significant contributors in each year.
- Interactive costs of the air vehicle/engine.

11. Report Generation; Design Iterations - Systems costs and benefits (or payoffs) are calculated for selected component improvements by executing the baseline program with variations offered by improved designs.

The form of this model's output will also require some consideration. Because costs have time values, it will be necessary to consider both discounting and escalating from some constant or "Datum Year" on out to the limits of the engine's life cycle in the "Horizon Year". Moreover, appropriate ranges of the cost-driving functions will be required to facilitate sensitivity testing.

FMEA APPROACH TO OPERATION/SUPPORT COSTS

During development of a DTLC Model it often becomes necessary to restate the objectives of its use, as each routine in the analytic methodology is selected. This occurs because there are usually too many approaches (rather than too few) to estimating the contributing elements.

FMEA APPROACH TO OPERATION/SUPPORT COSTS (Cont'd)

For example, parametric methods for treating engine development and acquisition cost are offered in the Rand report[7], based on a "time of arrival" technique. Another and more design-specific method is described by Atkinson[8] which involves the "Maurer Factor"* in predicting acquisition cost. Some parametric approaches are also available for calculating maintenance cost indices. Gregor, et al[9] in particular have acquired a propulsion system maintenance estimating relationship (MER) set by correlation analysis of recent tactical aircraft experience. That MER is specified in terms of maintenance man hours/flight hours (MMH/FH) and one would need complementary MER's for maintenance parts cost (P.\$/FH) as well as cost per maintenance man hour (M\$/MH) to complete the equation.

$$\$/Fh = (M\$/MMH)\ (MMH/FH) + P\$/FH \qquad (1)$$

Some broad conclusions can also be drawn from an ARINC report[10] that quotes engine support costs at 6-10%/year of engine inventory. That is:

$$\text{Engine/Support } \$/\text{Year} = K \frac{\$\ \text{Acquisition}}{\text{Engine}} \times I \qquad (2)$$

Here, K is a coefficient with a range of .06 to .10 and I is the average number of engines in inventory during the year of interest.

These and other cost Estimating Relationships (CER's) are useful for planning programs and for establishing benchmarks or references. However, they do not fulfill the needs of an engine design activity that is intent on reducing the cost of engine ownership because they do not provide the essential service of <u>identifying engine design features that drive cost</u>.

One approach to identifying design-controllable maintenance costs is based on the use of a failure mode effect analysis (FMEA). Arnzen's[11] early description of a rigorous FMEA technique exemplified its use in addressing the reliability of safety-of-flight equipments. He systematically identified the known failure modes of components of a typical system together with their probability of occurrence. Then, the failure modes were carried through a functioning system to identify their effects in terms of mission success. He showed how attention to critical component redundancy, derating and other reliability design techniques could result in improved mission reliability.

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* The author suggests that the Maurer Factor with a periodic commodity update would be a continuely useful Cost Estimating Relationship.

FMEA APPROACH TO OPERATION/SUPPORT COSTS (Cont'd)

Mission impairment is certainly a major concern in engine design, as are the consequences of part failures and wearout. The FMEA is a prospectively useful way to calculate these costs if the maintenance consequences are well as the mission consequences are considered. A significant measure of engine maintenance is also performed for preventive and routine servicing reasons - and, with some modification, the FMEA lends itself to integrating these cost-drivers into the total maintenance cost consequence analysis. Figure 5 lists the consequences addressed by a conventional FMEA in comparison with those that require consideration in total maintenance consequence analysis.

FMEA LOGIC ROUTINE

A FMEA method for calculating support costs in dollars per engine flight hour and dollars per engine fleet year, or other period (e.g., fiscal quarter) is best explained by example of its application to a simple subsystem. In this case, an engine low oil level indicator subsystem is examined. The system schematically described in Figure 6 consists of a float, a switch, a cockpit mounted socket and a bulb. Each component is numbered and its failure modes identified by a convenient notation.

A worksheet, as shown in Figure 7, is used to enter known information about each component's failure modes, and their likely (if not known) distributions and values. Unless otherwise known the Weibull distribution is selected as the "best likely fit" and the most useful for component reliability estimation. (Reference 12 examines the problem of estimating engine component reliability). The Weibull distribution takes the form

$$R(t) = EXP\left[-\left(\frac{t-ta}{m}\right)^{b}\right] \qquad (3)$$

Where:

ta = The lowest time (or stress) at which failures occur*

m = The location parameter (better known as MTBF when B = 1.0)

b = The shape factor (b less than 1.0 indicates decreasing failure rate, b = 1.0 indicates a constant failure rate, and b greater than 1.0 is indicative of wearout or accelerating failure rates).

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* In most analyses, a = 0 is assumed for time (but not stress) dependent failures.

FMEA LOGIC ROUTINE (Cont'd)

The engine system effects of failure modes are entered and their maintenance consequences are identified. This task requires development of an aid such as the maintenance sequence diagram shown in Figure 8.

The maintenance consequences of interest (besides the failure distributions) are those that the engine or aircraft designer can influence. Of these, accessibility is quantified by determining the number of components that have to be removed and replaced just to get at the offending part. The cost of the replaced part (which may include items consumed, such as gaskets); the man hours devoted to the task; and, the minimum time in "Calendar Hours" are other necessary considerations. Another useful product is the incidence of hazardous failure modes, which is often required by MIL-STD-882 (13).

Because of the number of variables, a computer-aided analysis is often a necessity, and a typical sub-routine, shown in Figure 9 performs as follows:

(a) Clock - Failures in this system model occur in discrete time intervals. The clock keeps track of this information and passes it on to other portions of the LCC program.

(b) Parts in Service - Elapsed time on components currently in service (fleet component summary) is advanced. The use schedule will be used in this calculation. If several generations of components are currently in service, their elapsed time is also incremented.

(c) Failure Calculation - Using the failure distribution information, the number of failures is calculated via hazard rate analysis.

(d) Components Remove, Reinstall, and Replace - Cost involved in removing and reinstalling components in order to gain access to the failed part, and in replacing the failed part is calculated in this section. One part of this calculation would be the use of a learning curve to adjust for maintenance learning effects.

(e) Component Update - An update of the replaced parts will be entered into the fleet component summary.

(f) System Safety Evaluation - Component by component system safety evaluation will be performed for all failed components, and, a system safety summary will be tabulated.

(g) Total Cost - Total maintenance material cost is calculated for the failures. This total cost will be adjusted by inflation and discount factors.

FMEA LOGIC ROUTINE (Cont'd)

By executing the routine for the low level oil indicating system previously described, and having information tabulated in Figure 10, the subsystem's cost per flight hour are calculated as shown there and in Figure 11. The results shown in Figure 10, constitute an iterable baseline. We would next logically expect to evaluate design improvements for their cost reducing prospects. Most, such iterations will require execution of a complete model because a part having improved life characteristics is likely to have an increased acquisition and/or development cost. However, there are usually a few design choices that become a matter of "acquisition/development cost-indifference". Taking the latter case, for convenience, we can examine the impact of decreasing accessibility to the bulb while simultaneously increasing its reliability - as might be the case for providing improved heat dissipation. Figure 11 illustrates a typical plot of cost reduction as a function of bulb reliability improvement. A change in accessibility of .5 man hours per event to .75 man hours/event is incurred. In this example, a probable reliability improvement is three (3) times the baseline reliability, with the net result of increasing cost. Hence, the change is contraindicated and should not be pursued.

FMEA - ENGINE SYSTEM EXAMPLE

A full-up engine FMEA will require attention to as many as fifty (50) or more components or subsystems as have just been described. However, our interest in cost consequences and some knowledge of the expected maintenance concept lead to convenient methods of grouping the effects.

By way of example, a light utility/trainer aircraft is postulated. Merrill (14) and others suggest requirements for a four (4) place, high performance, aircraft, designed for that service, and equipped with twin turbofan engines. A possible baseline engine configuration for that aircraft is shown in Figure 12, with its modular groups; designated by the conventional Work Unit Code (WUC) scheme. Its mechanical arrangement is assumed to consist of:

- a single stage fan group, with an externally mounted oil tank
- a combination axial/centrifugal compressor
- an annular combustor
- single stage HP & LP turbines
- a tower shaft accessory drive package, on which the oil/fuel pumps are mounted, and a power extraction fitting is provided for aircraft use.
- an electronic fuel control package and integral fuel metering valve is assumed.

FMEA - ENGINE SYSTEM EXAMPLE (Cont'd)

Other engine provided accessories would include a sensor group (fuel control inputs) and possibly bleed extraction provisions. The trend towards use of remotely mounted gear-boxes as described by Gaertner [15] and other is acknowledged by postulating a power-take-off shaft (not shown) and hence airframer supplied starter, hydraulic pumps and fuel boost pumps. (This trend, incidently, eases the engine LCC analyst's job by making the engine/airframe demarcation somewhat clearer.)

How this engine will be serviced, inspected and maintained is also of interest. A first cut at the engines' accessibility parameters is accomplished by constructing an engine maintenance sequence diagram as shown in Figure 13, which includes an initial assumption on the airframe provided provision for engine access. The blocks list the engine groups, the arrows describe the progression of groups needing removal (and subsequent replacement) to access other groups, and the parenthesized values show the estimated time in man-hours needed to accomplish each step in the sequence.

An assumption on the engine owner's plan for maintenance or "maintenance-concept" is the next necessity. We can expect that he will follow his tried-and-proven existing practice, unless some major benefit is otherwise realized. That assumption is reflected in the maintenance concept described in Figure 14.

A last-but-not-least need is for a set of input values regarding aircraft utilization, the value of maintenance man-hours at various levels and other cost elements. In practice, these must be supplied in part by the engine design activity, the airframe designer and the prospective engine buyer/owner. The author's guesses at such values for this purely hypothetical example are shown in Figure 15.

We are interested in determining the owner's maintenance cost for the baseline engine design and maintenance concept. That solution is obtainable by using the aforementioned data/models and the previously described computer routine. However, we should recall that: (1) money too has a "time-of-arrival" value; (2) the owner's inventory will not be a square wave, but a time varying function; and, (3) his aircraft utilization function will vary in some proportion to inventory. For these reasons, the time series plotted cost of maintenance is found to be the most convenient output form as illustrated in Figure 16.

A baseline design maintenance cost estimate is usually an interesting conversation piece that plots into aesthetic curves (sometimes after smoothing) and furnishes the awe-factor of large numbers. Hopefully, it also challenges our engineering instinct to do something constructive with it, and that's what Design-to-Life-Cost is all about.

FMEA - ENGINE SYSTEM EXAMPLE (Cont'd)

In this example, several design-controlled cost-drivers suggest themselves. However, when dealing with a full-up engine installation, most changes will be found to incur some front-end cost. Hence two design iterations, shown in Figure 17, are postulated together with their lumped front-end (development plus fleet acquisition) costs (assumed by the author for this sample problem).

The cost impact of these iterations is then plotted in Figure 18, to illustrate these results.

(1) Iteration (1) involved improving the MTBF of the electronic fuel control computer by using "high-reliability" parts and employing a reliability conditioning or "burn-in" test. It is estimated to result in an increased mean time between unscheduled removal (MTBUR) and an increased interval between engine "trims". The calculated benefit: cost ratio is 2.7.

(2) Iteration (2) involves porting the engine at strategic points to permit borescope or fiber optic inspection. This change extends the interval between the tear down inspections by lessening the need for removing the engine to verify component integrity. Its calculated benefit: cost ratio is 21.6.

(3) Iteration (3) examines the combined impact of effecting both changes, to achieve a benefit: cost ratio of 13.5.

The task of successfully selecting and giving priority to worthy cost reductions, singly or in combinations, will call for a combination of design imagination and efficient analytical techniques.

FMEA EXTENSIONS AND A DEFINITION

The foregoing examples were intended to open discussion and interest on the worth of an FMEA-based engine LCC analysis. There are other design and maintenance decisions that affect engine maintenance costs and deserve systematic evaluations. One significant method is NAVAIR's Level of Repair or LOR, which includes component failure rates as cost drivers, and seeks a cost optimum balance of spare parts, AGE allocation and maintenance level designations (e.g., DOD or Contractor). With appropriate integration, the LOR and FMEA appear to be useful complements. It and other extensions of the FMEA are listed in Figure 19.

Mention of the LOR leads to comment on another engine component parameter that seems to deserve quantification in deference to maintenance cost reduction interest "Durability". It is mentioned frequently in engine literature and at least one specification [16] but has not (to the author's knowledge) been precisely defined or equated to anything. The term is sometimes used interchangeably with "mission-

FMEA EXTENSIONS AND A DEFINITION (Cont'd)

reliability" and sometimes it suggests "maintenance-reliability". However, the LOR and USAF's Optimum Repair Level Analysis (ORLA) both require definition of a cost driver that is a function of component durability and that is the "Repair This Station" ratio (RTS). RTS expresses* the percentage of parts that will pass a periodic inspection, after on-engine service of a specified time, and therein lies a needed definition. The author suggests:

"Durability is the probability that an engine component will operate, in the manner intended, for a specified time and, upon inspection by a prescribed method, shall satisfy design limits for return to service".

The probability distribution functions this parameter might exhibit are suggested subjects for other discussions, but an initial step would equate it together with reliability in a time function, thusly.

$$D(t) = R_{(t)} \times Y_{(t)} \quad \text{(Also shown in Figure 20)} \qquad (4)$$

Where: $R_{(t)}$ is the familiar reliability function and $Y_{(t)}$ is the prescribed inspection's process yield at time (t).

CONCLUSION

Cost of engine ownership has recently joined the list of design challenges made to the engine community. As one designer somewhat wryly stated:

"..today, Inherent/Design-to/Produce-to/Life Cycle/Cost Analysis and execution have risen as the New Technology, replacing the all-out, unilateral pursuit of performance and weight improvements of the past few decades". (17)

If there is one most significant aspect of engine ownership cost reduction, that is the reality that it cannot be done unilaterally. An aircraft engine, its aircraft and its mission have a profoundly interactive cost of ownership effect, (Figure 21). So, the engine designer, airframe designer and aircraft owner/operator must enter into willing partnership if their enterprise is to be cost-successful.

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* Its complement is the "Not Repair This Station" ratio or NRTS, so that 1-RTS = NRTS.

APPENDIX

NOTATION	DEFINITION
b	Weibull Shape Parameter
CER	Cost Estimating Relationship
D (t)	Durability or probability of Return-to-Service at time t.
EFH	Engine flight hour (Firewalls/Aircraft) X Aircraft operating hours (Block to Block)
FH	Flight hour.
M (k)	Characteristic Life of Component k (MTBF when b = 1.0 in the Weibull Distribution).
MAT (k)	Mean Access Time to the Kth Component.
MER	Maintenance Estimating Relationship.
R (t)	Reliability or survival probability at Time t.
Y (t)	Yield of Inspection process at Time t.

ACKNOWLEDGEMENTS

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CAPTIONS FOR ART

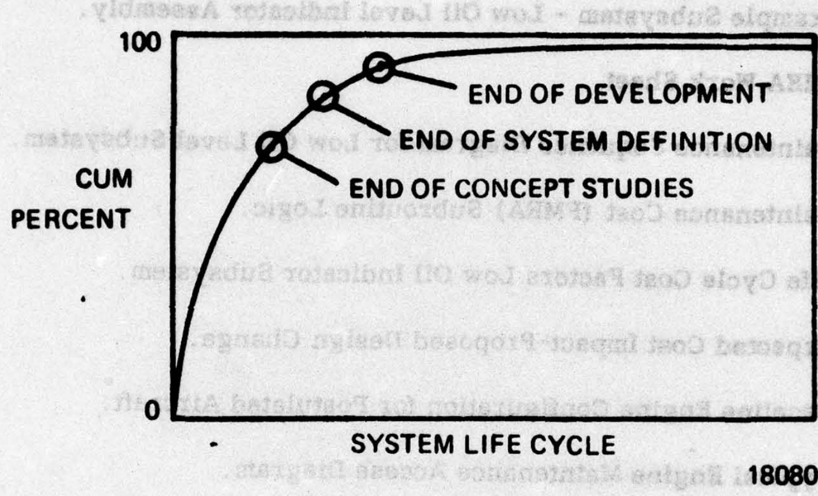

Figure 1. Time Phased Decisions Defining Life Cycle Cost From Reference 1.

ENGINE	APPLICATION	MODEL TYPE
F106 - CA - 100	"SCAD"; DECOY; USAF	LCC; "AVIONICS TYPE"
MODEL 471 - 11DX	SLCM, MISSILE, USN	DESIGN - TO - COST
TS - 120	TURBOGENERATOR (RFP), USA	LCC; "AVIONICS TYPE"
MODEL 455	ATEGG/APSI/JTDE, USAF	METHODOLOGY - ORIENTED : EMPHASIS ON INTERACTIVE COST
69 - T - 25	TRAINER, T - 37; USAF	CIP/PSP - DECISION AIDS
COMPONENTS	EXPLORATORY DEVELOPMENT, USAF/USN	LCC AS TRADE-OFF PARAMETER

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Figure 2. Some Recent/Current Teledyne CAE Programs Having LCC Aspects.

CHARACTERISTIC	TYPICAL AVIONICS LCC MODEL	IDEAL ENGINE LCC MODEL
EQUIPMENT CONFIGURATION	SEMI - INDEPENDANT ACCESS	SEQUENTIAL ACCESS
ENVIRONMENT	STEADY STATE	DYNAMIC
INVENTORY	SQUARE WAVE	TIME FUNCTION
DEVELOPMENT COST	FIXED	COST x RISK VS BENEFITS
INTERACTIVE COST (ENGINE - A/C)	NONE	SIGNIFICANT

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Figure 3. Comparison of Engines Vs. Avionics LCC Models.

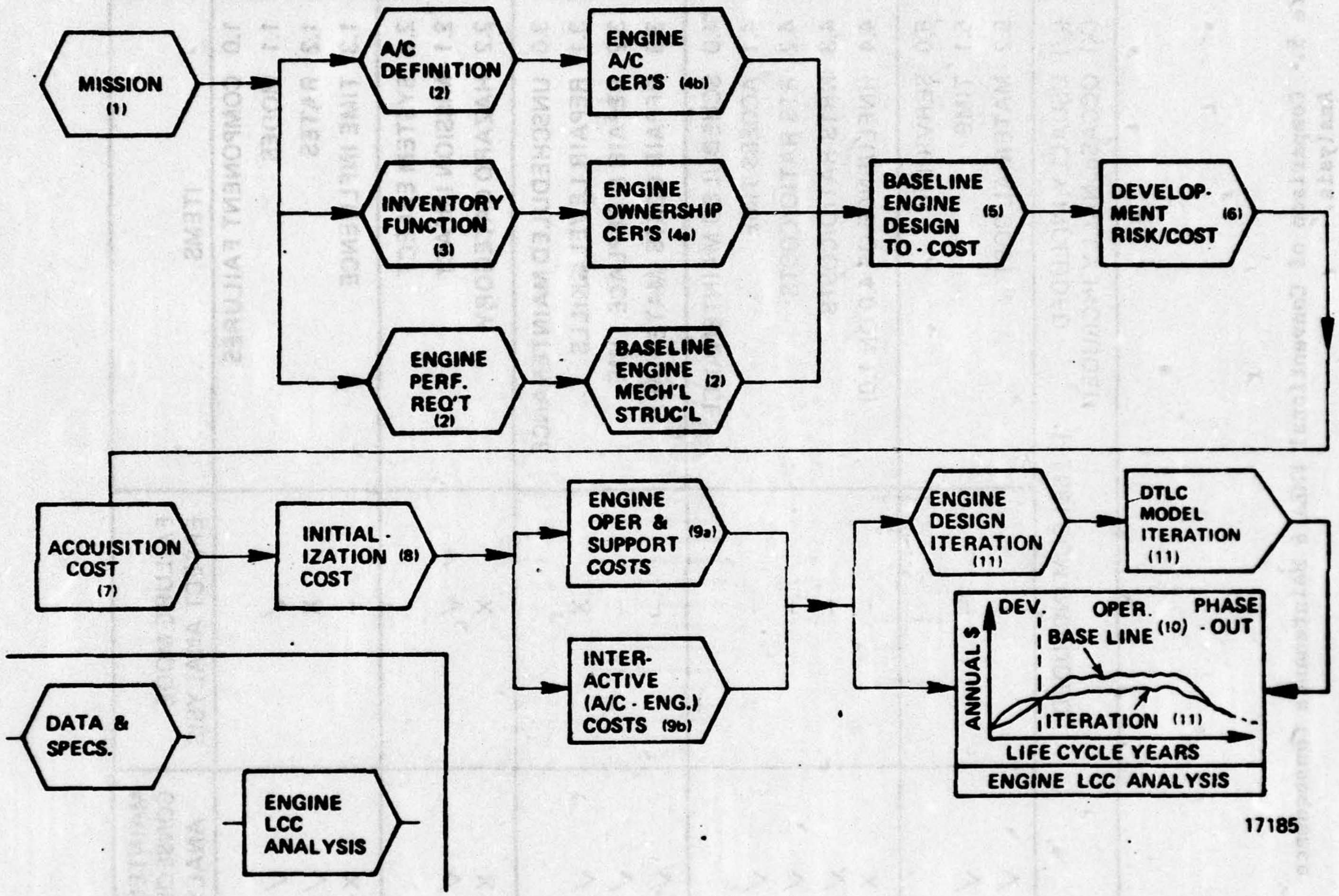

Figure 4. Engine DTLC Model - Logic Flow.

ITEMS	FAILURE MODE EFFECT ANALYSIS	MAINTENANCE CONSEQUENCE ANALYSIS
1.0 COMPONENT FAILURES		
1.1 MODES	√	√
1.2 RATES	X	√
1.3 TIME INFLUENCE	–	X
2.0 SYSTEM EFFECT		
2.1 MISSION IMPACT	√	√
2.2 HAZARD CATEGORY	X	X
3.0 UNSCHEDULED MAINTENANCE		
3.1 REPAIR LEVEL/SKILLS	X	√
3.2 REPAIR & REPLACE TIME	–	√
3.3 REPAIR COSTS (MATERIAL)	–	√
4.0 SCHEDULED MAINTENANCE		
4.1 ACCESS TIME	–	√
4.2 RTS RATIO/COSTS	–	√
4.3 NRTS RATIO/COSTS	–	√
4.4 (INFLUENCE OF 4.0 ON 1.0)	–	X
5.0 SERVICING		
5.1 TIME	–	√
5.2 MATERIAL COST	–	√

(√) USUALLY INCLUDED (–) SELDOM INCLUDED
(X) OCCASIONALLY INCLUDED

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Figure 5. Comparison of Conventional FMEA & Maintenance Consequence Analysis.

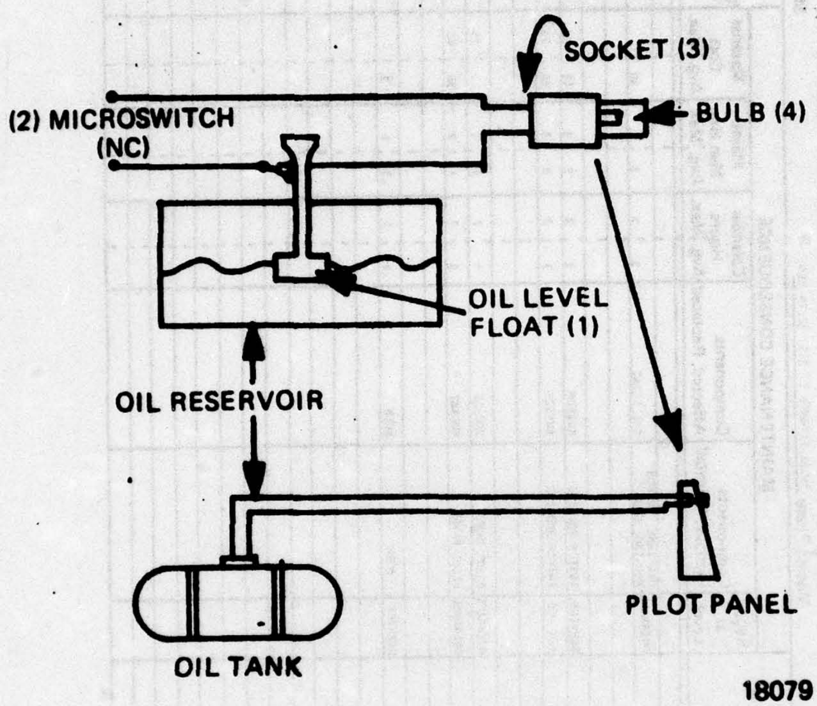

Figure 6. Low Oil Indicator Assembly.

TELEDYNE CAE

FAILURE MODE EFFECT ANALYSIS

Program TYPICAL

Model -

Prepared By - - Date -

Approved By - - Date -

Component SUBSYSTEM R/M I.D. No. Name LOW OIL INDICATOR TCAE P/N -

Mission Phase TOTAL FLIGHTS IN 3[illegible] HR. (= 750)

Sheet ___ Of ___

COMPONENT FAILURE MODE				ENGINE/SYSTEM LEVEL EFFECT	MAINTENANCE CONSEQUENCE									SYSTEM SAFETY EFFECT	
Case No.	DESCRIPTION	Probability			Repair at Level	Components Remove; Reinstall	Components Affected; Replaced	Calendar Hours Avg.	Calendar Hours Max.	Maint. Man Hrs. Avg.	Maint. Man Hrs. Max.	Material Cost Avg.	Material Cost Max.	Type Hazard	Compensation Provision
1.0	OIL TANK FLOAT														
1.1	STICKS	1.5	5500	NO WARNING	OVERHAUL	OIL TANK, SWITCH HOUSING, ETC.	OIL FLOAT	3	5	3	5	30		I	NEGLIGIBLE
2.0	MICROSWITCH														
2.1	FAIL OPEN	2.0	5600	INCORRECT WARNING	SERVICE	SWITCH HOUSING	SWITCH	1	2	2	3	15	25	II	MARGINAL
2.2	FAIL CLOSED	2.0	18000	NO WARNING	SERVICE	SWITCH HOUSING	SWITCH	1	2	2	3	15	25	I	NEGLIGIBLE
3.0	SOCKET														
3.1	INTERMITTENT	1.0	10000	INCORRECT WARNING	OVERHAUL	PILOT PANEL	SOCKET	5	7	1	2	15	25	I	NEGLIGIBLE
3.2	OPEN	1.0	10000	NO WARNING	OVERHAUL	PILOT PANEL	SOCKET	5	7	1	2	30	40	II	MARGINAL
4.0	BULB														
4.1	OPEN	3.45	700	INCORRECT WARNING	SERVICE	NONE	BULB	.5	1	.5	1	3		I	NEGLIGIBLE

Form T-705 9/72

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Figure 7. FMEA Work Sheet.

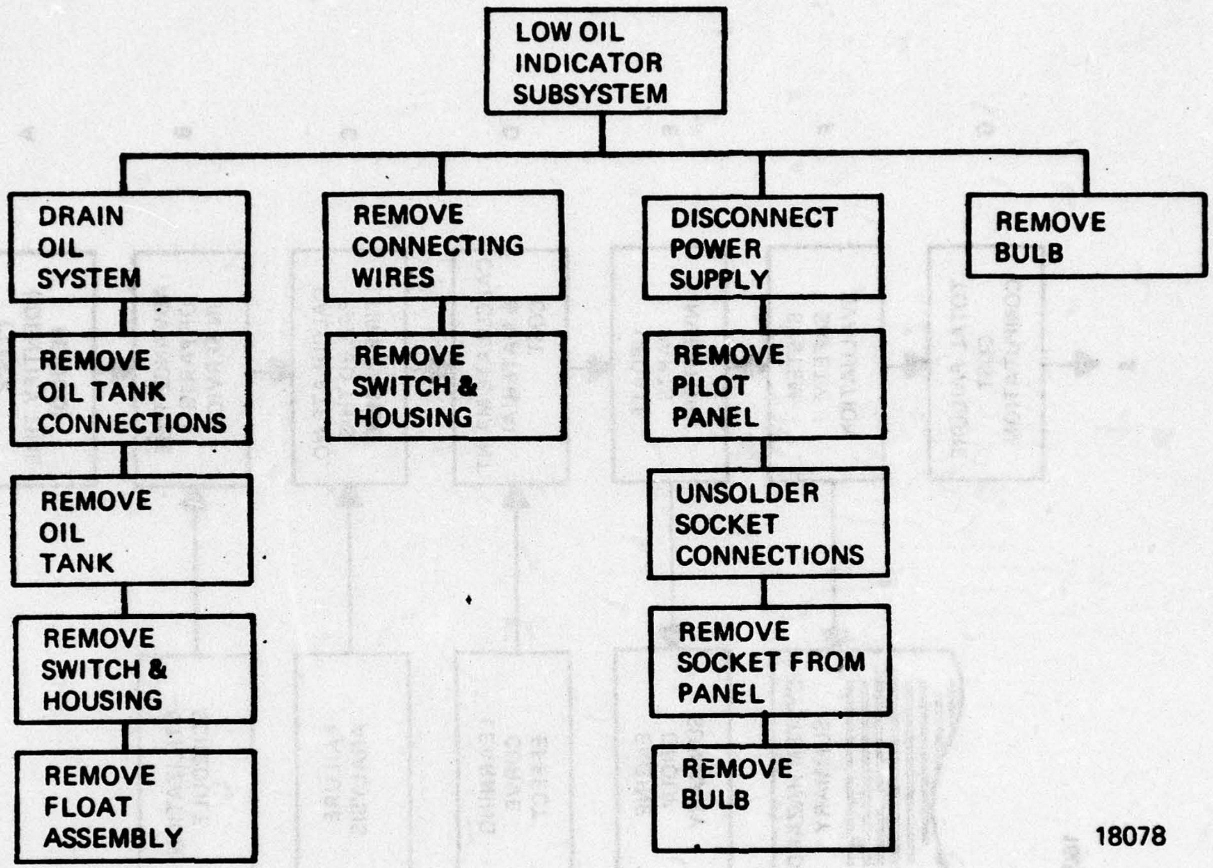

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Figure 8. Maintenance Sequence Diagram For Low Oil Level Subsystem.

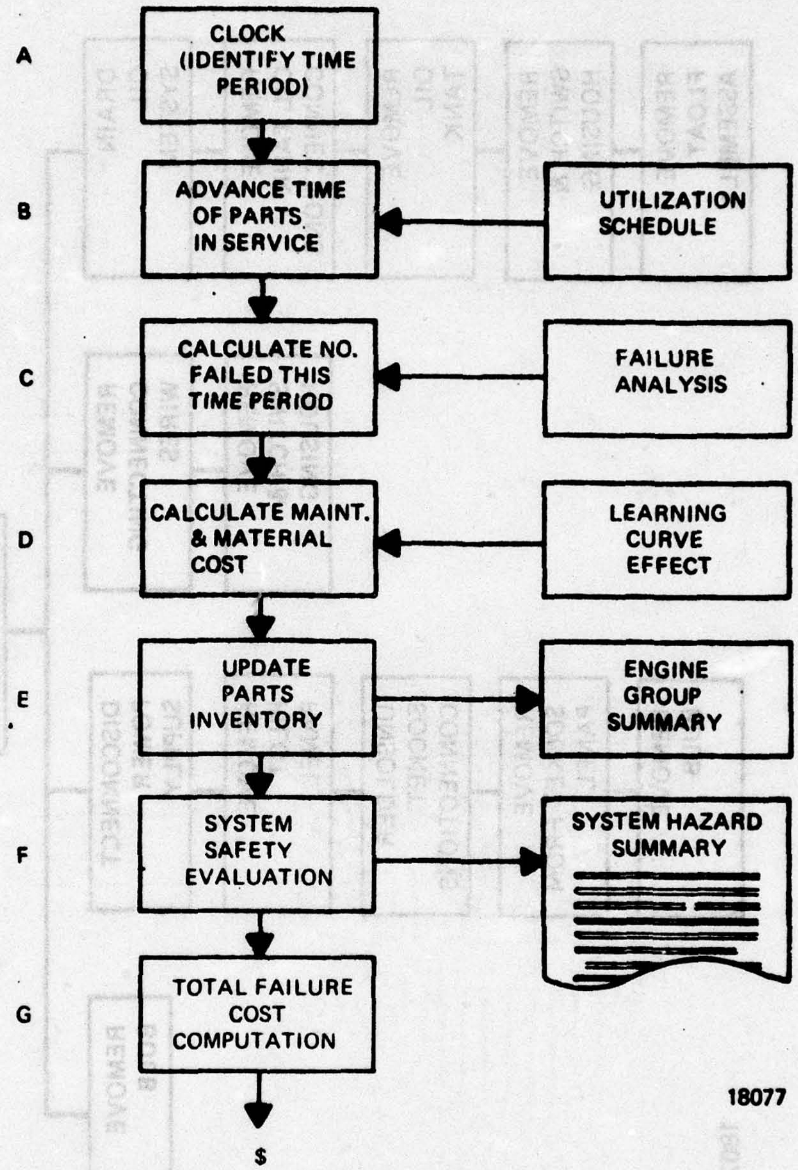

Figure 9. Maintenance Cost (FMEA) Subroutine Logic.

CASE NO.	% FAILED	TOTAL FAILED	MAINT. MAN-HOURS	HOURS FOR ITEM	MATERIAL COST PER ITEM	COST FOR ITEM
1.1	33	66	3	198	$30	$1980
2.1	25	50	2	100	$15	$ 750
2.2	1	2	2	4	$15	$ 30
3.1	26	52	1	52	$15	$ 780
3.2	26	52	1	52	$30	$1560
4.1	100	200	0.5	100	$ 3	$ 600
				506 TOTAL HOURS		$5700 TOTAL MATERIAL

200 SYSTEMS @ 3000 ENGINE FLT. HR (EFH)/SYSTEM
506 HOURS @ $10/HOUR = $5060
TOTAL COST FOR ALL FAILURES = $10,760
OR $.0179/EFH

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Figure 10. Life Cycle Cost Factors For Low Oil Indicator Subsystem (Baseline Design).

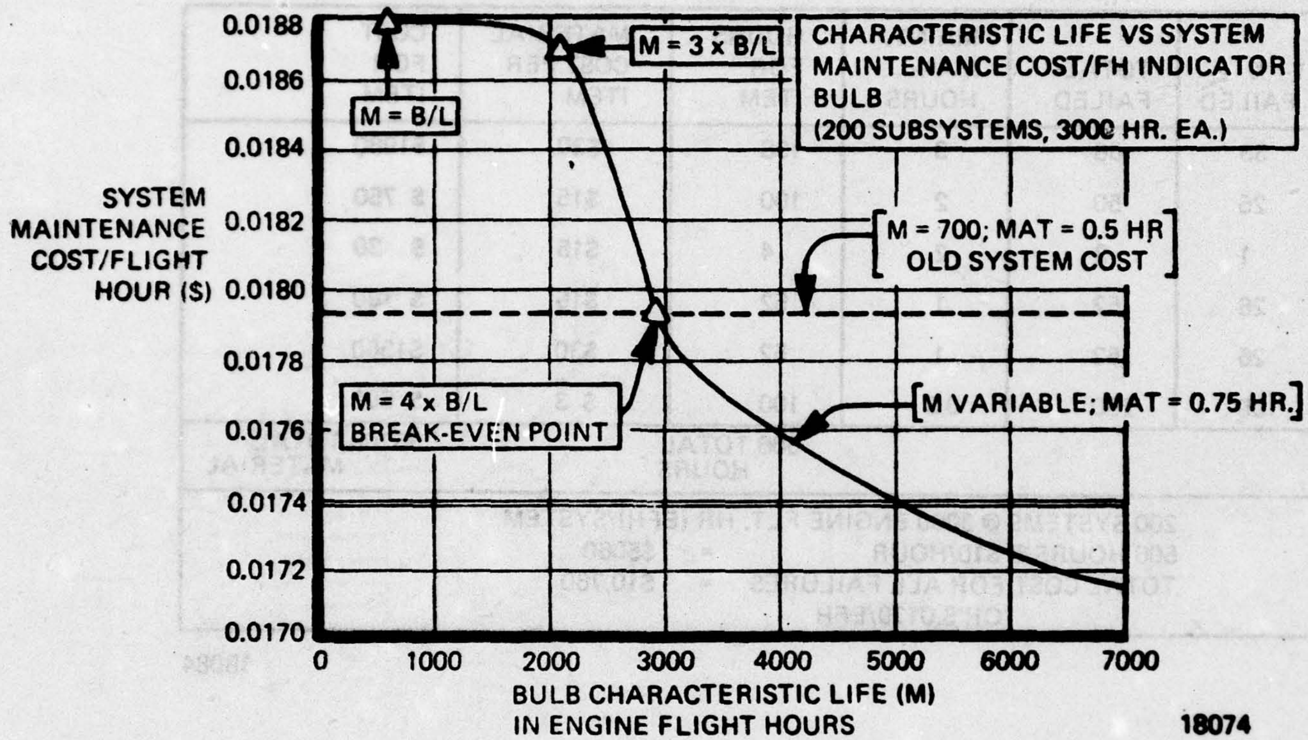


Figure 11. Expected Cost Impact - Proposed Design Change.

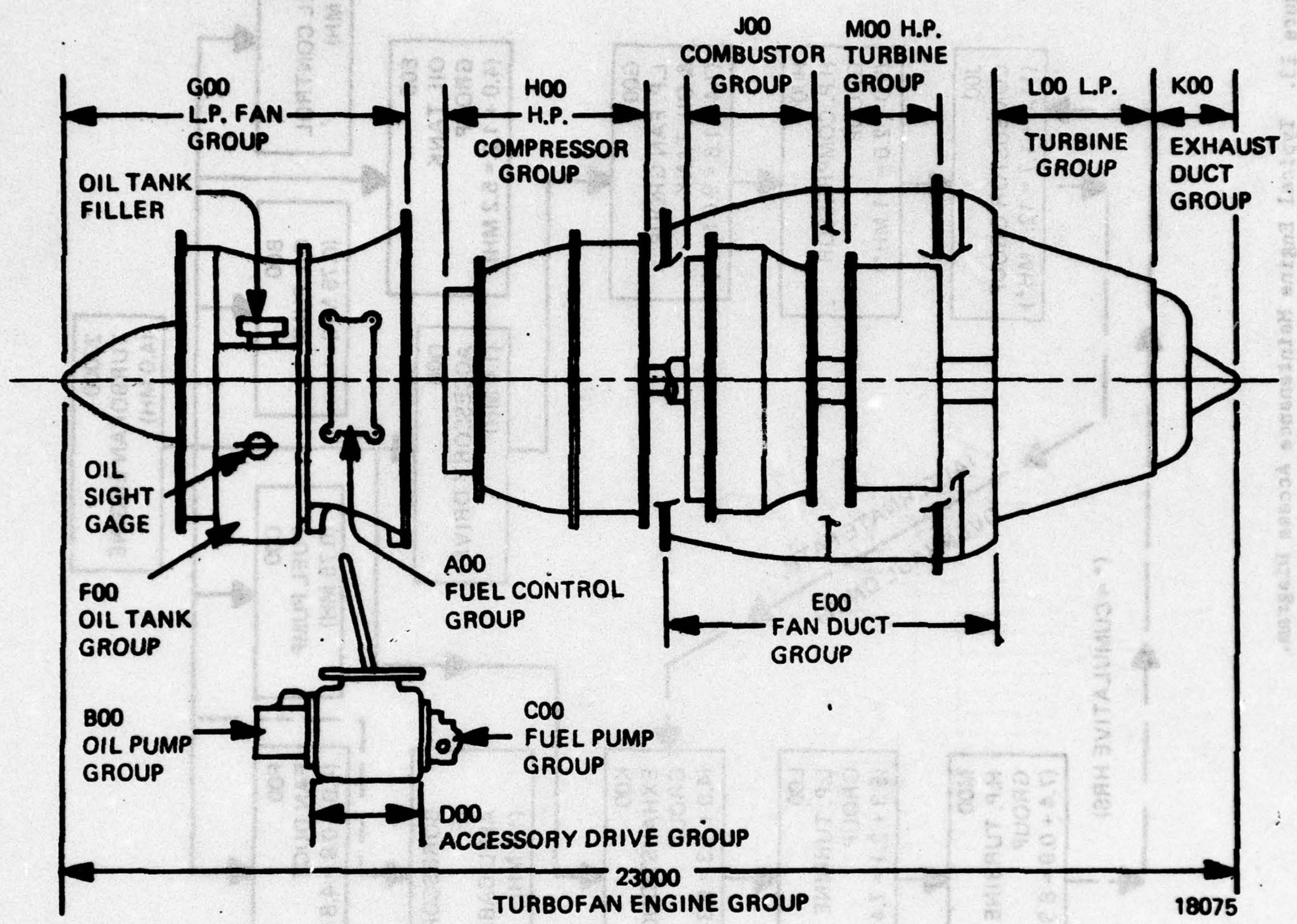


Figure 12. Baseline Engine Configuration (2 Each) For Postulated Aircraft.

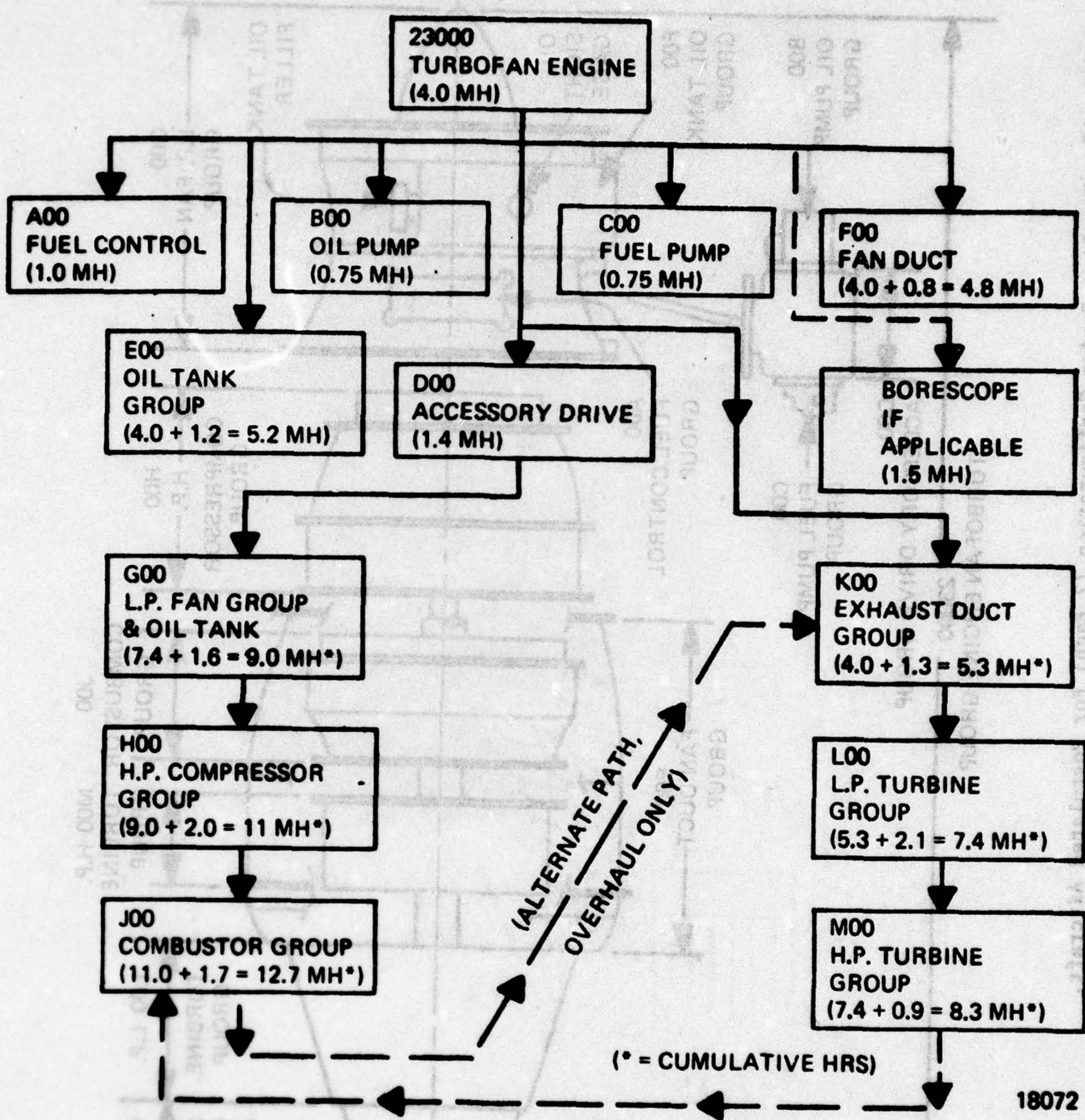


Figure 13. Typical Engine Maintenance Access Diagram.

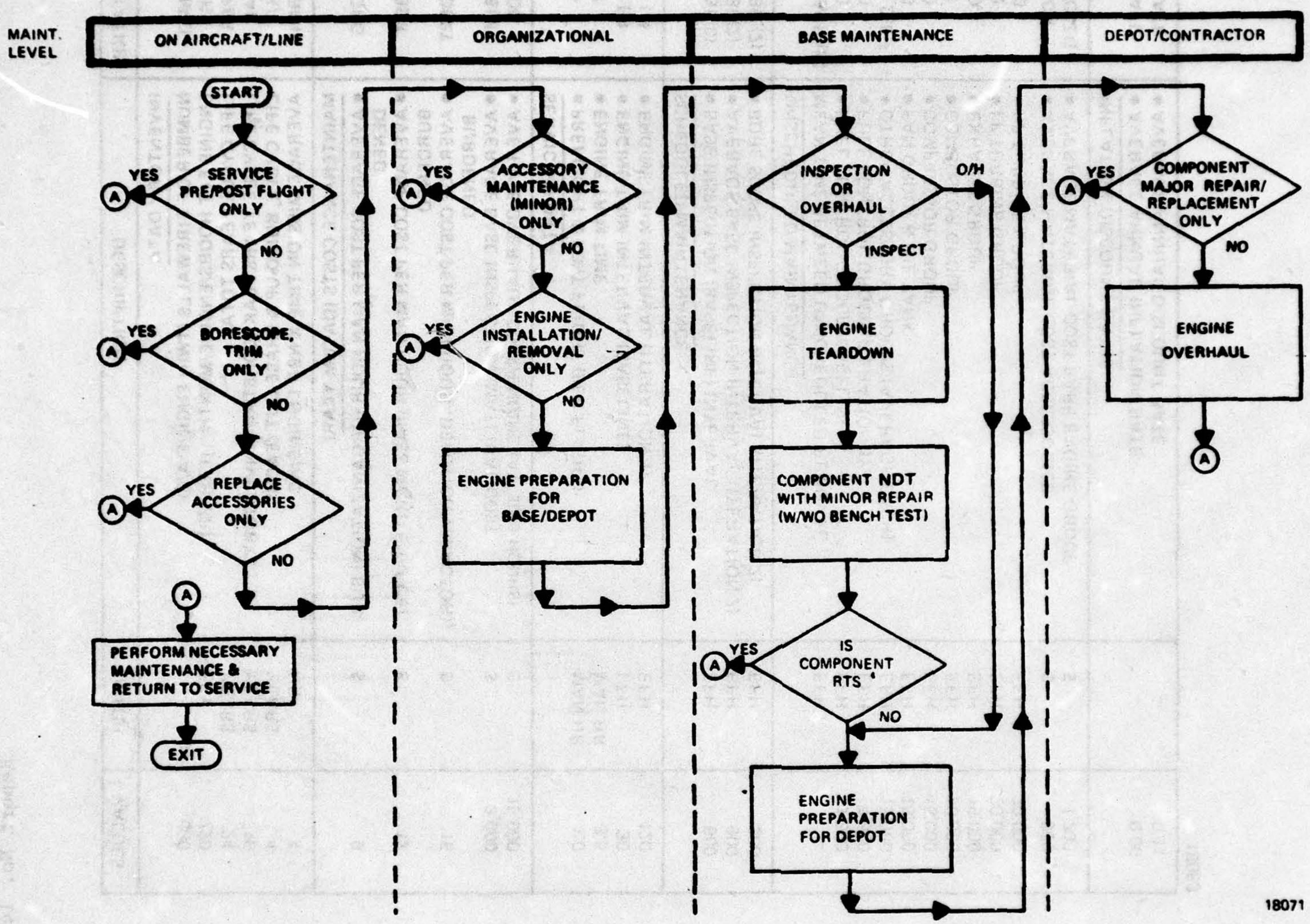


Figure 14. Typical Engine Maintenance Concept.

NOTATION	DESCRIPTION	UNITS	VALUES
	INVENTORY DATA		
IFWALL	NUMBER OF FIREWALLS (TWIN ENGINE A/C)	-	600
IEFHR	ENGINE FLT HOURS/ENGINE/MONTH " (EFH/YR)	EFY	720
NOPER	LIFE CYCLE YEARS TOTAL	YEARS	24
IPEAK	LIFE CYCLE YEARS PEAK (CONSTANT INVENTORY)	YEARS	16
IPOUT	LIFE CYCLE, BUILD-UP & PHASE OUT (EACH)	YEARS	4
DURMIS	AVERAGE MISSION TIME X NBH ENGINE/AC	HR	4
	MAINTENANCE COSTS (DATUM YEAR)		
ACORG	• AVERAGE COST PER MAN HOUR (ORGANIZATION) BURDENED	$	9
ACBSM	• AVERAGE COST PER MAN HOUR (BASE MAINTENANCE), BURDENED	$	12
ACDEPT	• AVERAGE COST PER MAN HOUR (DEPOT/CONTRACTOR), BURDENED	$	15
ACBIM	• AVERAGE BASE INSPECTION, MATERIAL COST	$	3,000
ACOC	• AVERAGE OVERHAUL COST/ENGINE (AT 3000 HOURS)	$	15,000
	SERVICING DATA		
SPP	• PREFLIGHT & POST FLIGHT (PER FLIGHT)	MAN HR	1.0
STT	• ENGINE TRIM TIME	MAN HR	3.5
STI (0)	• ENGINE TRIM INTERVAL (BASELINE)	EFH	30
STI (1)	• ENGINE TRIM INTERVAL (ITERATION 1)	EFH	120
	SCHEDULED MAINTENANCE		
SMBI (0)	• BASE INSPECTION (BASELINE) INTERVAL	EFH	600
SMBI (2)	• AVERAGE BASE INSPECTION INTERVAL (ITERATION 2)	EFH	900
SMBII (2)	• BORE SCOPE INSPECTION INTERVAL (ITERATION 2)	EFH	300
	UNSCHEDULED MAINTENANCE		
MTBUR (K)	MEAN TIME BETWEEN UNSCHEDULED REMOVAL	EFH	–
A00	• FUEL CONTROL GROUP (BASELINE)	EFH	1,500
A00	• FUEL CONTROL GROUP (ITERATION 1)	EFH	4,500
B,C,D,E,F	• OTHER ACCESSORY GROUPS (AVERAGE EACH)	EFH	15,000
G00	• FAN GROUP & OIL TANK	EFH	15,000
H00	• COMPRESSOR GROUP	EFH	45,000
J00	• COMBUSTOR GROUP	EFH	30,000
K00	• EXHAUST GROUP	EFH	15,000
L00	• LP TURBINE GROUP	EFH	20,000
M00	• HP TURBINE GROUP	EFH	20,000
AMCA	• AVERAGE MATERIAL COST ACCESSORIES	$	900
AMCBEG	• AVERAGE MATERIAL COST BARE ENGINE GROUP	$	1,200
	INFLATION/DISCOUNT RATES		
FRATE	• AVERAGE ANNUAL INFLATION RATE	–	0.06
DRATE	• AVERAGE ANNUAL DISCOUNT RATE	–	0.11

18083

Figure 15. LCC Data (Maintenance Cost) Typical Engine Program.

ITEM/YEAR →	1	2	3	4	5	6-20	21	22	23	24
DRIVERS										
IFWALL	75	225	375	525	600		525	375	225	75
HOURS/YR (000)	54	162	270	378	432		378	270	162	54
MISSIONS/YR (000)	14	41	68	95	108		95	68	41	14
SERVICE EVENTS										
PRE/POST FLIGHT $(000)	122	365	608	851	972		951	608	365	122
ENGINE TRIM $(000)	6	17	28	40	46		40	28	17	6
SCHEDULED MAINTENANCE										
BASE INSPECTION $(000)	313	939	1566	2192	2506		2192	1566	939	313
OVERHAUL $(000)	270	810	1350	1890	2160		1890	1350	810	270
UNSCHEDULED MAINTENANCE										
ADO $(000)	33	99	164	230	264		230	164	99	33
B,C,D,E,F $(000)	17	47	78	110	125		110	78	47	17
G,H,J,K,L,M $(000)	18	55	92	129	147		129	92	55	18
ANNUAL COSTS $(000)	779	2332	3886	5406	6226	99,390	5406	3886	2332	779
ADJUSTMENT FACTOR	0.98	0.93	0.89	0.85	0.81	–	0.39	0.37	0.35	0.34
ANNUAL ADJUSTED $(000)	763	2169	3459	4595	5043	43,377	2108	1438	816	269
SAVINGS										
ITERATION 1 SAVINGS $(000)	12	37	62	87	99	1,485	87	62	37	12
ITERATION 2 SAVINGS $(000)	101	304	506	708	809	12,135	708	506	304	101
ITERATION 3 SAVINGS $(000) (1+2)	113	341	568	795	908	13,620	795	568	341	113

18082

Figure 16. Time Varying Maintenance Cost Typical Engine Program.

ITERATION NO.	ENGINE DESIGN CHANGE DESCRIPTION	COST DELTA "FRONT-END"
1	RELIABILITY IMPROVEMENT OF ELECTRONIC FUEL CONTROL (GROUP A00)-USES "HIGH-REL" PARTS & 40 HOUR BURN-IN TEST	$300,000
2	BORESCOPE PORTS TO ACCESS GAS GENERATOR	$400,000
3	COMBINES 1 & 2	$700,000

18088

Figure 17. Two (2) Hypothetical Design Iterations & Front-End Cost Deltas.

ITEM/ITERATION NO.	FUEL CONTROL 1	BORESCOPE 2	BOTH 3
PRIOR BASELINE COST $(000)	130,422	130,422	130,422
UNADJUSTED SAVINGS $(000), LIFE CYCLE	1,980	16,182	18,162
ADJUSTED SAVINGS $(000), LIFE CYCLE	1,104	9,023	10,127
FRONT END COST $(000)	300	400	700
ADJ. SAVINGS - LESS COST:			
• BENEFIT, $(000)	804	8,623	9,427
• % OF BASELINE	1	13	14
BENEFIT - COST RATIO	2.7	21.6	13.5
PRIORITY	2	1	–

18087

Figure 18. LCC (Maintenance) Cost Impact of Two Design Iterations (Singly and in Combination).

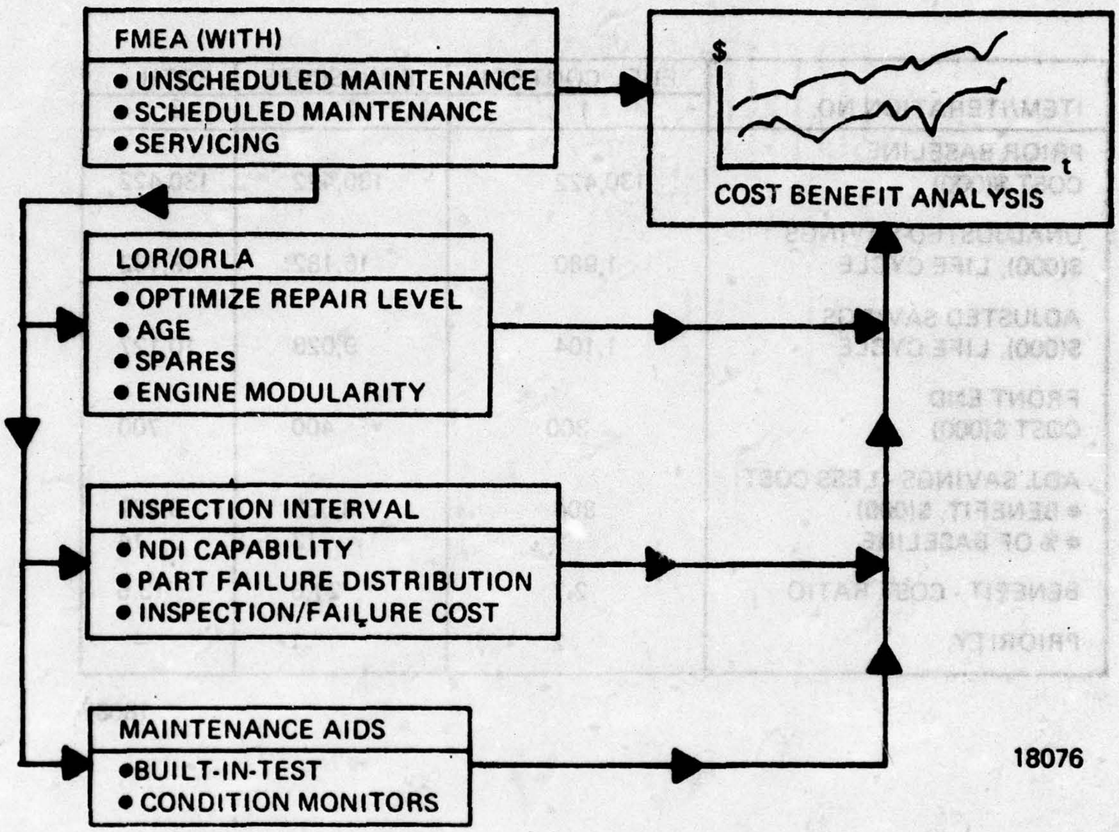


Figure 19. FMEA Extensions.

PROPOSED DURABILITY DEFINITION

"DURABILITY IS THE PROBABILITY THAT AN ENGINE COMPONENT WILL OPERATE, IN THE MANNER INTENDED, FOR A SPECIFIED TIME AND, UPON INSPECTION BY A PRESCRIBED METHOD, SHALL SATISFY DESIGN LIMITS FOR RETURN TO SERVICE."

DURABILITY EQUATION

$$D(t) = R(t) \times Y(t)$$

WHERE:

$R(t)$ IS THE RELIABILITY OF THE COMPONENT TO TIME t.

$Y(t)$ IS THE PRESCRIBED INSPECTION'S PROCESS YIELD AT TIME t.

18089

Figure 20. "Durability" Proposed Definition and Equation.

PHASE/ACTIVITY	ENGINE DESIGNER (1)	AIRFRAME DESIGNER (2)	AIRCRAFT OWNER/OPERATOR (3)
BASELINE DESIGN	• LCC DATA ACQUISITION • DESIGN TO OPTIMUM COST	• PROVIDE ENGINE COST SENSITIVITY DATA • OPTIMIZE ENGINE INSTALLATION	• DESCRIBE HIS MISSION/ MAINTENANCE PLAN • IDENTIFY HIS COST DRIVERS
DESIGN ITERATIONS & OPTIMIZATION	• IDENTIFY REQUIREMENTS LCC IMPACT • PROPOSE COST OPTIMIZED CHANGES	SUPPORT CHANGE EVALUATIONS WITH BEST COST ESTIMATES	• EVALUATE CHANGES • SCRUTINIZE INITIAL COST-DRIVING REQUIREMENTS
SERVICE USE	• ASSESS SERVICE USE DATA • SUPPORT/ADVISE ON COST REDUCTION CHANGES IN DESIGN/ OR MISSION	• PROVIDE SERVICE USE DATA • SUPPORT IMPROVEMENTS	• PROVIDE SERVICE USE DATA • UPDATE COST DRIVERS • INCORPORATE USEFUL CHANGES

18081

Figure 21. Some Contributions of Engine Design, Airframe Design, and Aircraft Owner/Operator to Engine Ownership Cost Reduction.

Robert McGinnis

Rockwell International

BS in Math from Baldwin Wallace

MS from University of Southern California

5 years maintenance experience in USAF

9 years logistics experience on F-111, F-15, B-1 and space shuttle.

Responsible for demonstration, verification and analytical trade-off techniques on thses programs.

Warranty Guarantee and Contractor Exposure To Cost Penalties

The following report discusses the types of cost penalties, adjustments and other considerations which were identified after review and analysis of an RIW Contract accepted for use on current program. Each paragraph identified a specific type of penalty or consideration, the amount of contractor risk or exposure to cost penalties, a parametric analysis (as applicable), and identification of critical areas on which management attention should be focused.

I. **Excessive Unverified Failures**

The contractor receives additional funds for only unverified failures in excess of 30% of the total returns. The first 30% is charged as normal maintenance actions under the basic warranty, and the contractor is only paid $100 for each repair in excess of the first 30%. The important aspect of this requirement is to assure the contractor includes consideration of the first 30% in his basic warranty contract by increasing his inherent failure rate by 30%, thereby increasing the dollar value of the initial warranty repair contract, or unit cost of the procured item (whichever means the contract allows).

II. **Warranty Period**

The warranty period is 60 months (5 years) for the original procurement, 60 months for Option I, 48 months for Option II, and 36 months for Option III. The risk to the contractor is in the inflationary factors that are involved over such a long time span. As an example, the cost of adding additional personnel and/or equipment if required to reduce the turnaround time, will be considerably higher five or ten years downstream than it is at the time of the proposal effort. This lengthy exposure period must be considered when accepting any degree of risk associated with the cost penalties discussed in the following paragraphs.

III. Annual Cost Adjustments

The Turnaround Time (TAT) adjustment (reference paragraph VII is calculated every 6 months, but the adjustment is made only every 12 months. The annual adjustment requirement means that the contractor is exposed to as many as ten separate sets of cost penalties. One additional problem related to this requirement is that many of the formulae have constants assigned to parameters that will vary from year to year as a function of inflationary factors and reliability growth (increased MTBF's).

IV. ECP's

The contractor must be aware of the requirement to incorporate, at no delta cost, engineering changes to improve reliability and support requirements. The contractor should perform trade studies involving the cost of the ECP versus the warranty penalties for excessive amounts of failures (low MTBF) and turnaround times. This type of trade study requires resources in terms of computer time and analytical personnel; this effort should be included in the original warranty cost estimates/ proposal.

V. **Two Repair Facilities**

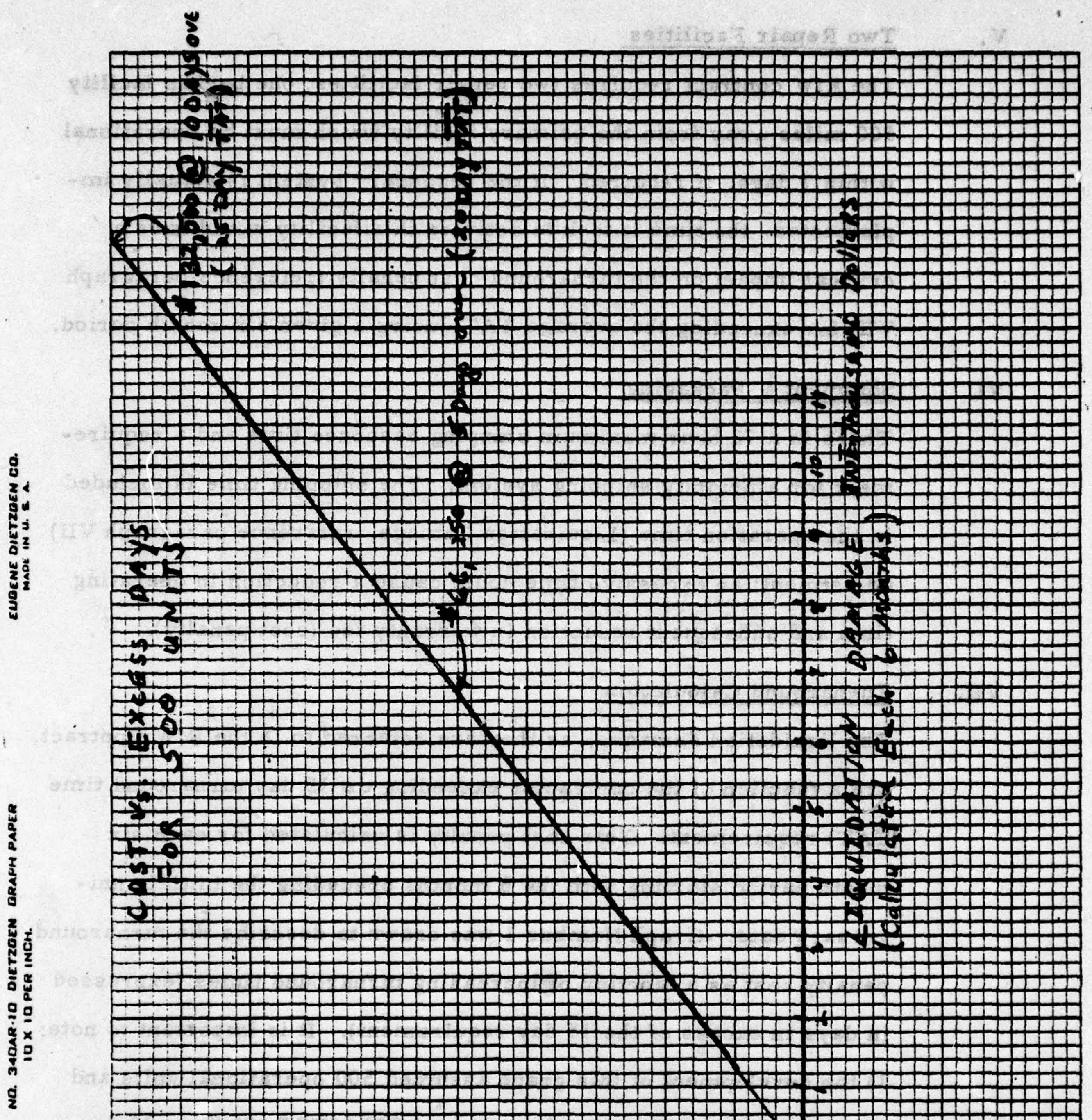
The RIW contract requires two repair facilities; one backup facility 500 miles away from the primary facility which must be operational within 7 days, if required. If the secondary system is actually implemented, the time it took to activate this facility would have a critical impact on the turnaround cost penalty (reference paragraph VII) for exceeding the average TAT during a given six-month period.

VI. **Shipment & Packaging**

There is a 72 hour maximum shipping response time and a requirement for a priority shipping system. The shipping time is included in the operation time (Liquidation Damage, reference paragraph VII) adjustment; an excessive time could cause a reduction in operating time and subsequent reduction in warranty fee (cost penalty).

VII. **Turnaround Calculation**

The liquidation damages, as they are referred to in the RIW Contract, are a function of the contractor exceeding the 15 day turnaround time (TAT) requirement. This cost penalty is calculated for each six month period starting with the 6 months preceding the initial anniversary date. Graph Number 1 was drawn to describe the turnaround penalty cost as a function of increasing turnaround times (expressed in days in excess of the 15 day requirement). It is important to note: 1) the development of this graph assumed 500 operational units and the capability of achieving the required 500 MTBF; 2) for a 25 day TAT the 6 month penalty is $132, 500 and for a 20 day TAT it is $66, 250; 3) the TAT is the most critical parameter in the RIW Contract due to the sensitivity of the cost penalty to small changes in the TAT.

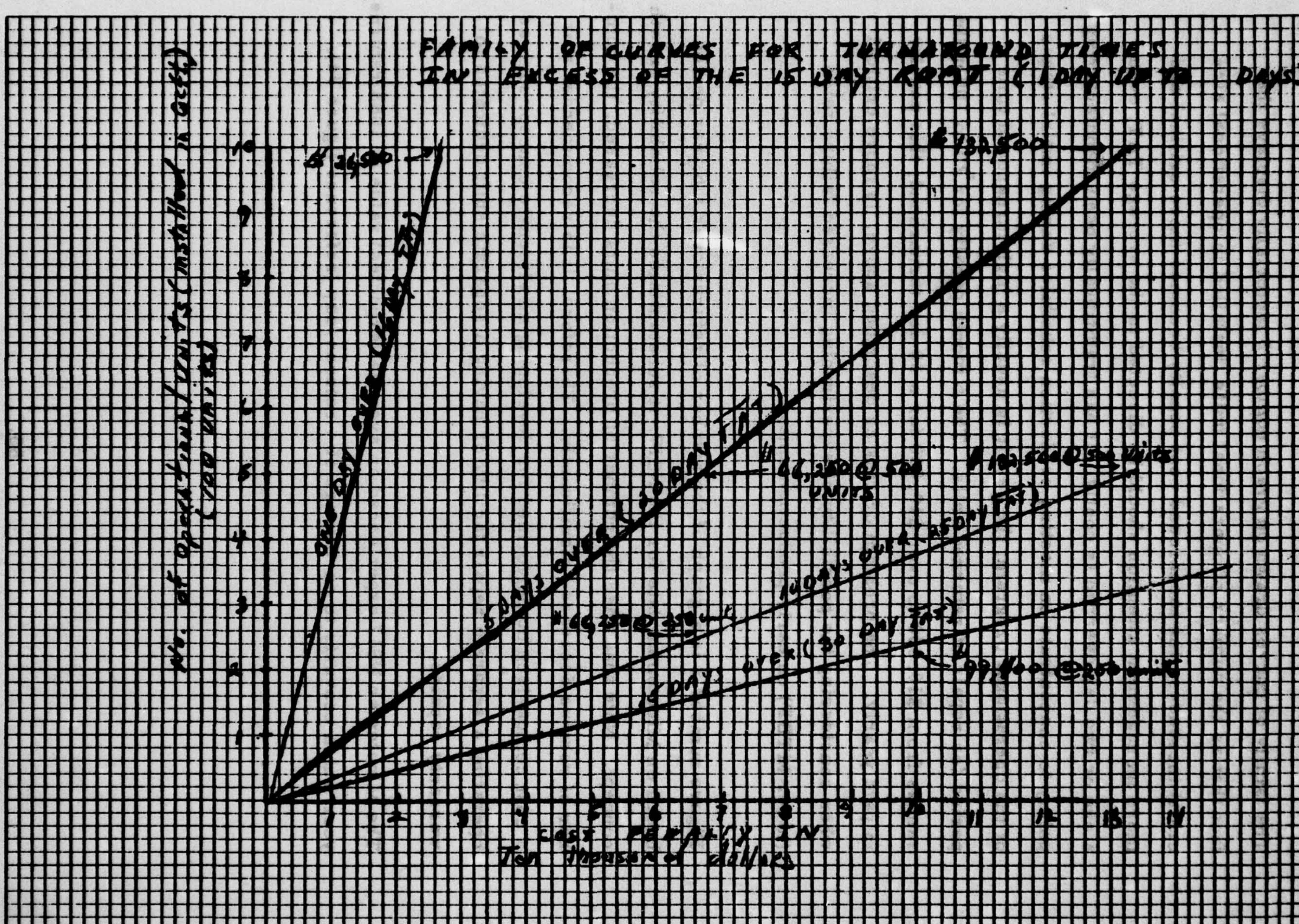


Graph Number 1

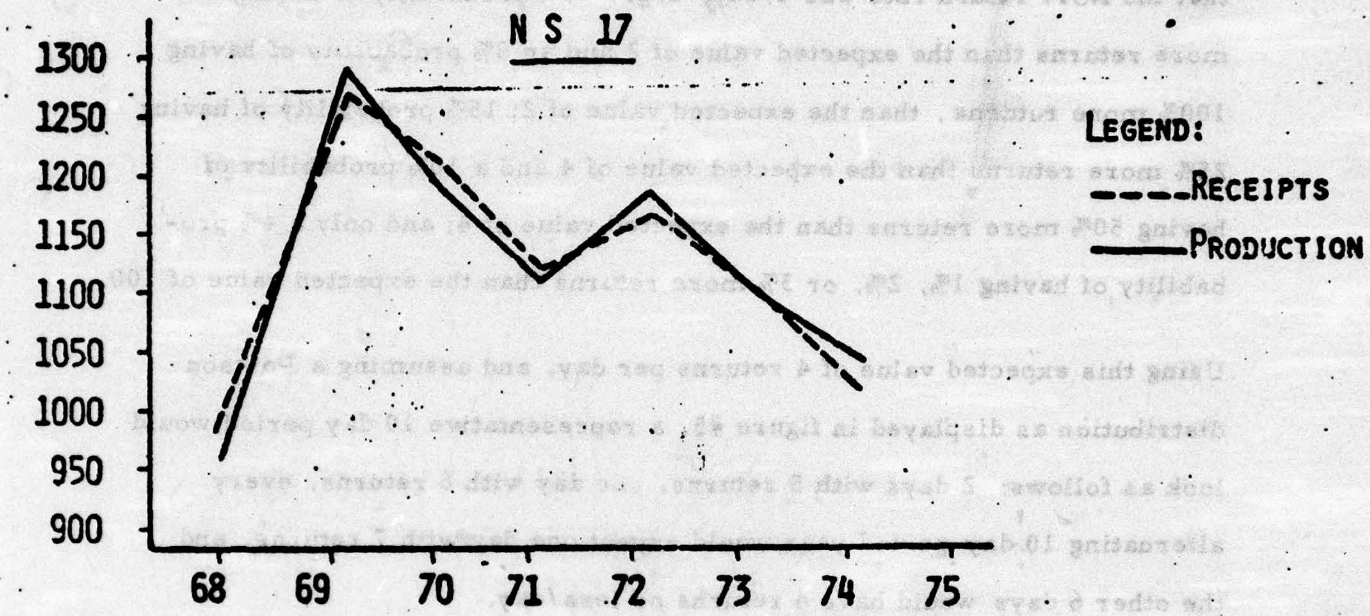
The family of curves drawn on graph number 2 pictorially displays the fact that as the number of operational units (installed in operational aircraft) increases, the turnaround cost penalty becomes more critical and more management attention should be directed to the average TAT; even a one or two day overrun is costly. It has traditionally been manufacturing policy to concentrate on meeting production schedules during initial stages of the operational program; the result is usually a high turnaround time period for repair of returned units. The 6 month penalty for 20 to 100 units ranges from $10,000 to over $40,000 for a 30 day turnaround; this penalty is paid yearly. The problem or risk as described above, is more critical when considering the possibility of experiencing increased failure rates (lower MTBF) on early production units.

Figure number 3 is a graph of the number of returns over a 6 year period based on Minuteman data for the NS17, it substantiates the reliability growth concept. Note that after the number of production units decreased, the number of returns decreased significantly. Therefore, it is recommended that a cost comparison be performed for developing an alternate concept such as operating a separate repair facility or having a separate shift dedicated to warranty repairs.

The Minuteman NS17 experienced an average (expected) value of 1068 returns/year which converts to an average of 4 returns/day (reference figure #4).



Graph Number 2



GRAPH NUMBER 3

Figure Number 5 displays a family of curves; the top curve displays the probability of experiencing exactly the expected number of repairs/ day; the second displays the probability of experiencing exactly one more return/day; the third and fourth curves display two or three returns/day over the expected value.

These graphs indicate the critical range is from 2 to 8 returns/day(Note that the NS17 return rate was 4/day) e.g., 18% probability of having 50% more returns than the expected value of 2 and an 8% probability of having 100% more returns, than the expected value of 2; 15% probability of having 25% more returns than the expected value of 4 and a 10% probability of having 50% more returns than the expected value of 4; and only a 4% probability of having 1%, 2%, or 3% more returns than the expected value of 100.

Using this expected value of 4 returns per day, and assuming a Poisson distribution as displayed in figure #5, a representative 10 day period would look as follows: 2 days with 5 returns, one day with 6 returns, every alternating 10-day period year would expect one day with 7 returns, and the other 6 days would have 4 returns or less/day.

It is obvious from the above examples that manning requirements could have a critical impact on the TAT requirement of 15 days. The question is, which level of return rate should you use in determining the number of men (servers) to allocate to the repair of returned items.

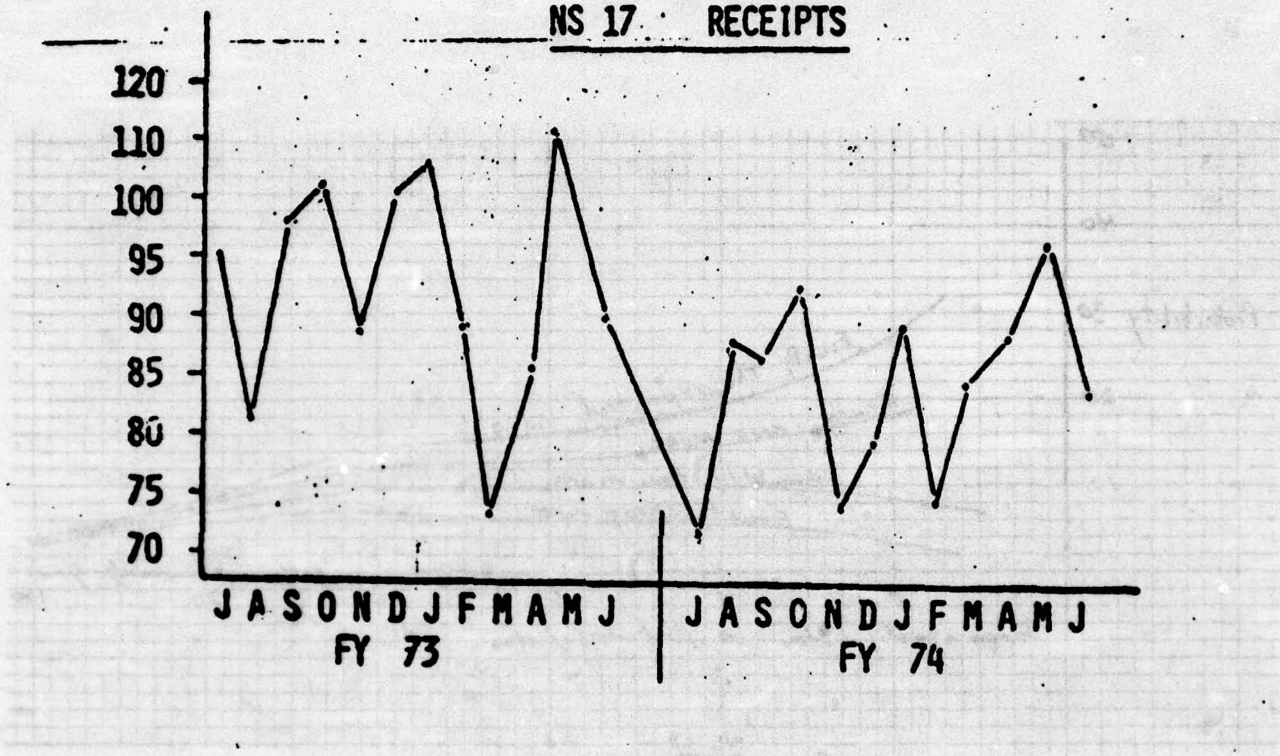


FIGURE NUMBER 4

YEARLY NS17 RETURNS

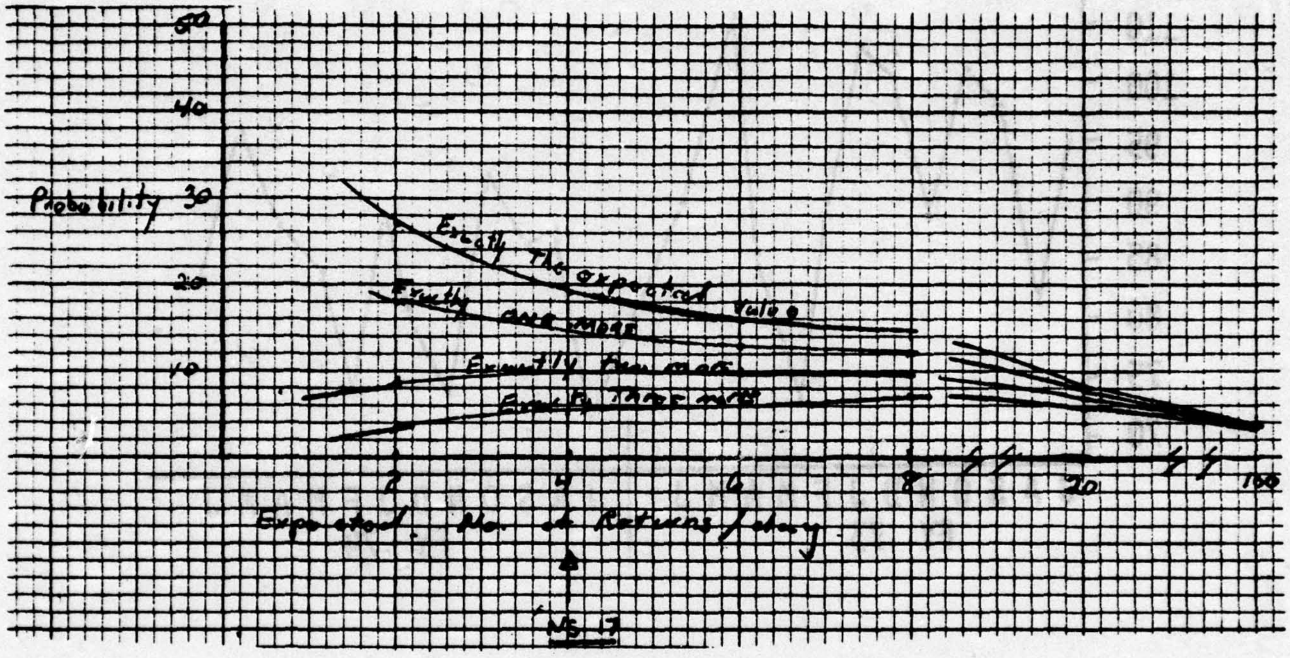


FIGURE NUMBER 5

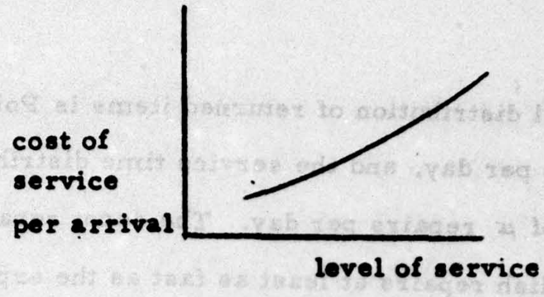
Assume the arrival distribution of returned items is Poisson with a mean rate of λ returns per day, and the service time distribution is exponential with a mean rate of μ repairs per day. The depot repair facility must be able to accomplish repairs at least as fast as the expected arrival rate λ. This is expressed as follows:

$$\rho = \frac{\lambda}{s\mu}$$

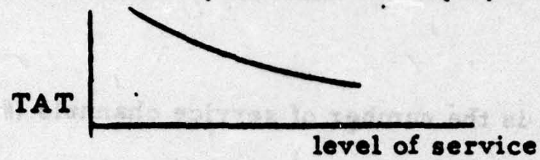
where: s is the number of service channels (# of servers) and p must be less than one (unity),

The que length, and waiting times, which impact the TAT, are dependent on p; if p is allowed to exceed .9 the que length would approach infinity. If we decrease the value of p by adding additional servers (increasing the value of s), the % of idle time (1 - p) of the servers will increase, however, the mean TAT will decrease due to the decrease in the waiting time.

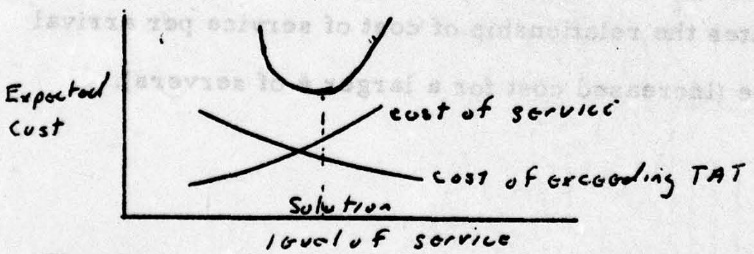
The problem is to assure that the value of p remains less than .9 and since μ and λ are fixed, the problem reduces to determining what the optimum level of service for the queueing system should be (determine values). The following graph indicates the relationship of cost of service per arrival and the level of service (increased cost for a larger # of servers).



The more servers the smaller your TAT as displayed in the following graph:



It is obvious that to decrease your TAT you must decrease your waiting time which requires an increase in your service rate (increase in the level of service), which in turn will cause an increase in the cost of service per arrival. The most obvious solution is to minimize the service cost, but on the other hand, an excessive waiting time will result in a large TAT which will cost money in terms of the warranty penalty. Therefore, the optimum solution is to select the point on the following curve which will determine the level of service which minimizes the total of the expected cost of service and the expected cost of exceeding the TAT which is caused by waiting for the service.



The above analytical process is over simplified to provide a general understanding of the problem, the actual support system requires consideration of other variables in the detailed analysis. There are many existing models

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and analytical processes that should be investigated and the specific support process may require development of a unique determination or simulation model. Autonetics currently has a queing model which will calculate: 1) the number of servers required to reduce the utilization rate to below 90% and 2) the expected que length, 3) expected weighting time.

The following is a summary of the queing analysis and related algorithms:

$$L_q = \sum_{n=s}^{\infty} [n-s] P_n = \frac{P_0 \left(\frac{\lambda}{\mu}\right)^s \rho}{s!\,(1-\rho)^2}$$

$\rho = \lambda/\mu s$ OR FRACTION OF TIME THE SERVERS ARE BUSY (EXPECTED)

$\mu_n =$ SERVICE RATE FOR THE OVERALL QUEING SYSTEM

$$\mu_n = \begin{cases} n\mu, & \text{if } 0 \le n \le s \\ s\mu, & n \ge s \quad (\text{All servers are busy}) \end{cases}$$

n = NUMBER OF UNITS IN THE SYSTEM

S = NUMBER OF MGE SERVERS (PARALLEL SERVICE CHANNELS)

$P_n(t)$ = PROBABILITY THAT EXACTLY CALLING UNITS ARE IN THE QUEING SYSTEM AT TIME

QUEING ANALYSIS

$$W_q = \frac{L_q}{\lambda}\ ; \quad W = W_q + \frac{1}{\mu}\ ; \quad L = \lambda\left(W_q + 1/\mu\right) = L_q + \lambda/\mu$$

WHERE: μ = MEAN SERVICE RATE

L_q = EXPECTED QUE LENGTH

W = EXPECTED WAITING TIME (INCLUDES SERVICE TIME)

W_q = EXPECTED WAITING TIME (EXCLUDES SERVICE TIME)

λ = MEAN ARRIVAL RATE

MULTIPLE-SERVER MODEL: IF $\lambda < S\mu$, SO THAT MEAN ARRIVAL RATE IS LESS THAN THE MAXIMUM SERVICE RATE, THEN

$$P_0 = 1 \Big/ \sum_{n=0}^{s-1} \frac{(\lambda/\mu)^n}{n!} + \frac{(\lambda/\mu)^s}{s!} \sum_{n=s}^{\infty} \left(\frac{\lambda}{s\mu}\right)^{n-s}$$

$$P_n = \begin{cases} \left(\frac{\lambda}{\mu}\right)^n P_0, & \text{if } 0 \le n \le s \\ \dfrac{\left(\frac{\lambda}{\mu}\right)^n}{s!\, s^{n-s}} P_0\ ; & \text{if } n \ge s \end{cases}$$

VIII. Unused Warranty Reimbursement

The contract allows for the contractor to return dollars to the customer for unused portions of the remaining warranty for each set/unit that is damaged to the extent it cannot be repaired. The decrease is a function of the number of remaining days of the warranty and dollar values allocated to each major component. The derivation of the dollar values was not provided,however, it was assumed that it related to the original amount of dollars bid for the total warranty period and some type of allocation to each unit by warranty day.

If there is a reduction in the number of operational aircraft, there would be a reduction in the number of units accumulating operating hours which would result in a reduction in the number of repairs. If the reduction of units involves an operational aircraft and the remainder of the operating units do not absorb the lost operating time due to the non-operating vehicles, the adjustment for the unused portion of the warranty is logical; however, if the same number of vehicles are operating, i.e., only one spare was damaged, the resources and dollars required to maintain the warranty will not be affected. The only result would be a lower probability of spare sufficiency for which the contractor should not be penalized. If a spare was lost at the start of period 1, it would cause a $1,440 reduction; for 10 units the cost would be $14,400.

If the damaged unit was one of the 500 operating units (aircraft) the result would be a decrease in operating hours for one operating system, or a reduction of 7 repairs over a 4 year period. Seven less repairs at $200/repair would be close to the $1,440 reduction in warranty which is the value arrived at using the RIW formula.

If one operational unit is lost, as described above, and the remaining 499 units absorb the lost operating time, the contractor would receive an increase in warranty fee of approximately $1,500 due to the adjustment for an increase in average operating time (AOT) reference Item IX. The number of warranty repairs will be unchanged, however, the $1,500 savings will offset the $1,440 penalty which was due to the decrease in warranty time period. The $1,500 savings will not be accrued if the lost or damaged item (unit) was a spare; however, the contractor still suffers a $1,440 reduction in the maintenance contract, and the actual number of repairs and related costs still remain unchanged because the operating time has not been reduced.

IX. Average Operating Time Adjustment

The equation used to calculate the operating time adjustment is mathematically incorrect due to improper placement of parenthesis (probably due to a typing error). It should be stated as follows:

$$.50 \left[.95 \quad (T_{68} - T_{ETI}) \right]$$

It is now stated as:

$$.50 \left(.95 \quad X \; T_{68} - T_{ETI} \right)$$

T_{68} is the predicted operating time which was used to bid the original warranty cost, and T_{ETI} is the estimation of the actual or experienced operating time during the warranty period. The calculation of T_{68} is simple, accurate and equates mathematically to the calculation of T_{ETI}; however, the calculation of T_{ETI} includes the number of installed days which, by the recording process, includes shipping time. The result of including the shipping time is that the T_{ETI} calculation will be less than the predicted (T_{68}) value even if the predicted 68 OH's/month are actually achieved (experienced). For a 68 hour average operating time and 500 aircraft installed units, the T_{ETI} should equal T_{68} which is calculated to be 358,000 hours. However, with a ten day shipping time included in the achieved T_{ETI} calculation, the T_{ETI} value will be 14,450 hours less than the T_{68} value of 358,000 hours. This results in a \$6,863 yearly penalty for a ten day average shipping time, with each delta day increase in the average shipping time costing approximately \$600 each year or \$3,000 over 5 years.

As displayed on Figure #6, the shipping time is not as critical, in terms of risk, as is the average Turnaround Time (TAT). Therefore it is not as important in terms of administrative control but is important in terms of assuring that this cost is considered in the original warranty contract.

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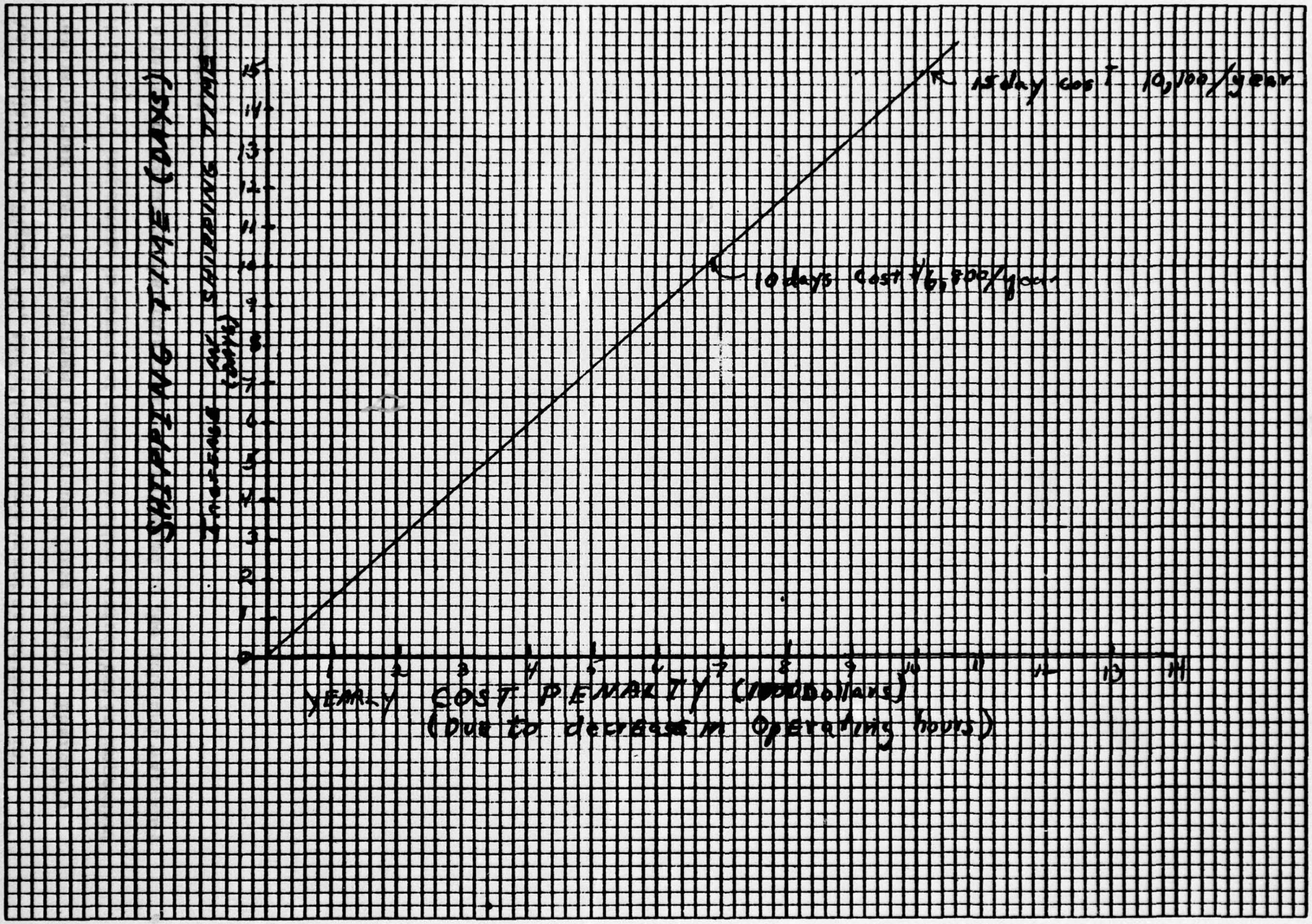


FIGURE NUMBER 6

X. MTBF Guarantee

Figure No. 7 describes the cost penalty for not achieving the MTBF requirement in terms of an increase in the number of consignment spares. The calculation of this spares quantity is a function of percent difference between the measured and guaranteed MTBF. The curve indicates that as the measured MTBF (M) approaches the guaranteed MTBF (G), the consignment spares quantity approaches zero. Conversely the greater the difference between the measured and guaranteed MTBF becomes, a corresponding or larger number of consignment spares are to be committed by the contractor at no additional cost to the buyer. This cost penalty and the turnaround penalty, which was previously discussed are the two critical (high risk) areas of the warranty contract. The consignment spares calculation is considered sensitive because of the large cost penalties accrued for small percentage changes in MTBF; in addition the problem is compounded by the sensitivity of the measured MTBF to a small sample size and the high probability of error associated with the calculation of the measured MTBF. The calculation of the number of additional consignment spares can vary considerably if the upper or lower confidence band is used instead of the expected time between failures which was based on a small sample. As an example the lower confidence band for the actual measured MTBF may be less than the guaranteed requirement thereby requiring some quantity of consignment spares; however, the upper band may exceed the guarantee and thereby not require any consignment spares. This probability of error (risk) needs to be negotiated in advance and/or agreement made to adjustments for consideration of the errors associated with small sample sizes. Too often the customer (DoD) is only concerned with consumer or customer risk (statisticians refer to this as "Type I" error) at the expense of producer or contractor risk (referred to as "Type II" error).

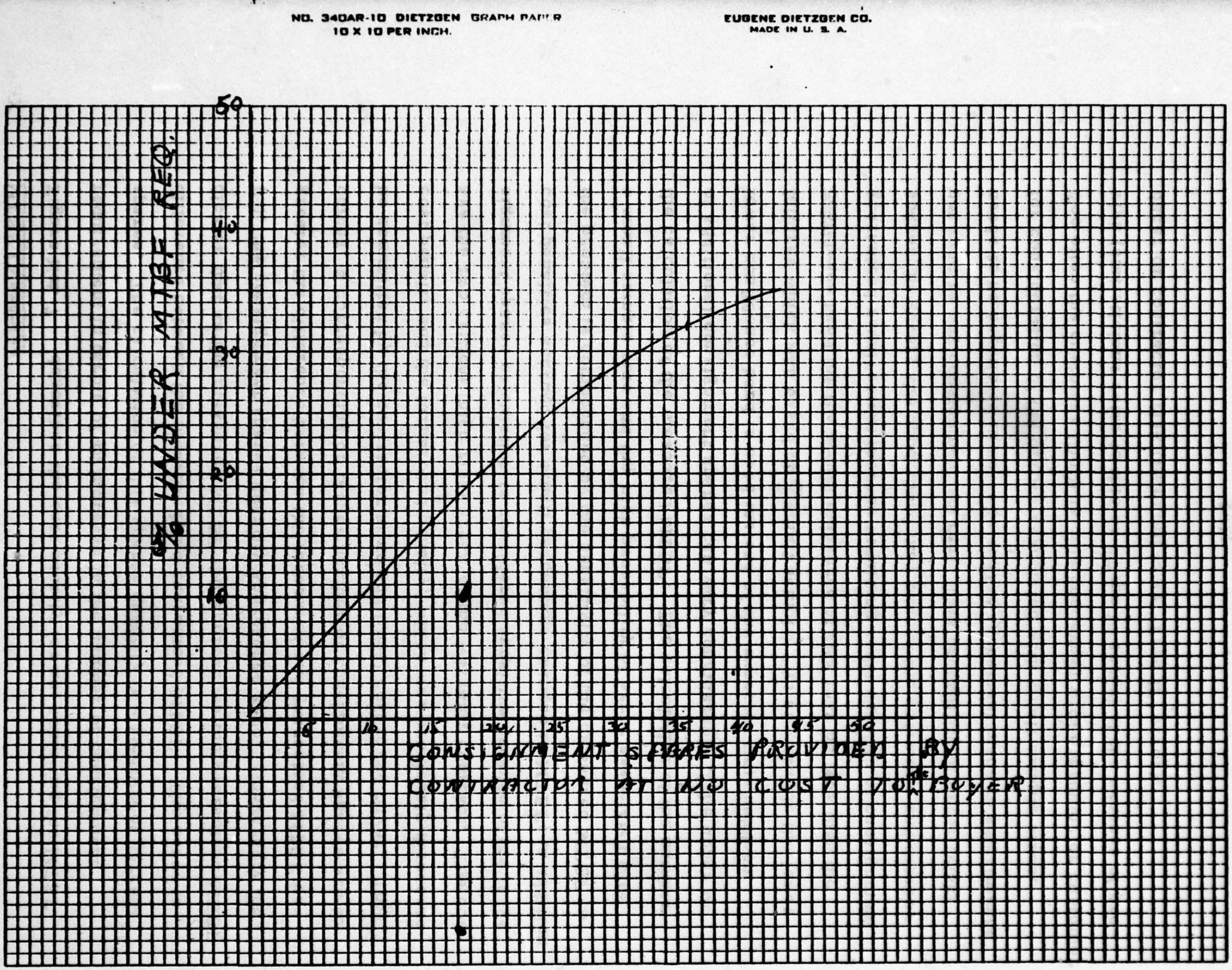


FIGURE NUMBER 7

Also there is an inconcistency in applying the warranty formulae for increasing or decreasing the number of consignment spares. As an example, for the contractor's first 6 month period the calculated MTBF was less than the requirement, however, the second 6 month calculation of MTBF showed an improvement and the contractor achieved the MTBF requirement. Under this condition the MTBF ratio (A) would be negative because the value of M is greater than G; therefore, the formulae is not valid and theoretically the contractor would not receive a return of consignment units. A statement is required that states "all consignment spares will be returned to the contractor if the value of A is negative"; which occurs whenever the contractor is meeting or exceeding the MTBF requirement.

The calculation of the number of consignment spares is based on a specified percentage (P) of the average number of installed sets over a six-month period. The derivations of the values of "P" were not provided. It is assumed that the value of P is based on a set probability of sufficiency using the Poisson distribution, which is sensitive to changes to pipeline (TAT) time and the MTBF. Therefore the initial lay-ins of spares, should be based on the MTBF requirement (G) and n_2, the delta increase or decreas in the quantity of spares required to maintain the same probability of sufficiency, should be based on the measured MTBF (M). For comparison eht following assumptions were made, and the values of n were calculated using the specific values of P as required by the warranty and the Poisson probability of sufficiency:

1) The MTBF allocation is as follows:

	Percent	MTBF	λ
LRU #1	80%	625	.0016
LRU #2	16%	3,125	.00032
LRU #3	2%	25,000	.00004
LRU #4	2%	25,000	.00004

These MTBF's were allocated in proportion to the percentage used in determining unused portion of the warranty Part IV paragraph 2.

2) $\bar{N}$ is set at 500 operating units (operational aircraft).

3) Average operating time/month for each unit is 68 hours (Ref Part IV, para 6).

4) 15 day turnaround is achievable plus 10 days for shipping.

5) Use period 1(22 - 33 MAC)which has an MTBF requirement of 500 hours (Ref Part V paragraph number 1).

6) Probability of sufficiency is set at 99%.

The target spares for the LRU #1 based on the warranty formulae, would be 77. Applying a 1.3 K factor for re-test OK's and using the probability of sufficiency technique, the recommended spares quantity also equals 77.

If the MTBF requirement (G) is 625 hrs. and the contractor demonstrates a 500 hr. MTBF (M = 500 hours) then the number of additional consignment spares, using the warranty formulae, is calculated to be 19 units. Using the probability of sufficiency calculation the number of additional recommended spares would be 16 units. Using the 19 units and a $10,000 per unit cost, the MTBF cost penalty would result in over 190,000 dollars.

XI. Warranty Data Requirements

The following list of data requirements are included in this report only to emphasize the level of effort that is involved with providing this amount of data:

A. Contractor Records of returned units

1) **Serial #**
2) **ETI reading**
3) **Condition (inspection)**
4) **Failure mode** *
5) **Probable cause** *
6) **Action taken for repair** *
7) **Manhours by labor category**
8) **Parts**
9) **Test results**
10) **Date to secured area**

B. Listing of units in Secure Storage

C. Unit Repair Cycle Time Report consisting of the following dates:

1) **Shipment to Gov. activity**
2) **Installation in aircraft**
3) **Removal from aircraft**
4) **Shipment to Contractor**

XI. Continued

D. Reliability Report

1) MTBF

2) Analysis of modes, trends, cost patterns

3) Corrective action

4) Effects of varying field environment

E. Warranty Population Report

Amount of warranty remaining for each unit.

F. Contract Price Adjustment Report

1) % of returns with unverified non conformance *

2) Average Turnaround Time *

3) Operating time measurement *

4) # lost units

5) Unit MTBF's

G. Annual Warranty Effectiveness Report *

H. Data Collection, Analysis, and Reporting Plan.

* All of the above data requires a sophisticated data management system, in addition, the asterisked items require analysis to be performed in order to produce the report.

- WARRANTY CONTRACT EVALUATION -

RISKS AND QUESTIONS

RISKS

UNVERIFIED FAILURES

WARRANTY PERIOD

COST OF PROGRAM OR DESIGN CHANGES

TWO REPAIR FACILITIES

TURNAROUND TIME (TAT)

UNUSED WARRANTY REIMBURSEMENT

MTBF GUARANTEES

WARRANTY DATA

UNVERIFIED FAILURES

UNDER 30% INCLUDED IN WARRANTY

OVER 30% CONTRACTOR PAID $100/ REPAIR

TESTABILITY VS TECHNICIAN ERROR

BID COST OF 1ST 30%

WARRANTY PERIOD

UP TO 5 YRS FOR ORIGINAL CONTRACT

THREE SETS OF OPTIONS (UP TO 12 YEARS)

CONSTANTS APPLIED TO FORMULAE

- NO INFLATIONARY FACTORS

- NO RELIABILITY GROWTH (STEP FUNCTION ONLY)

6 MONTH CALCULATIONS WITH ANNUAL ADJUSTMENTS

- NO RISK FACTORS BASED ON SMALL SAMPLES.

COST OF CHANGE VS WARRANTY PENALTY

COST OF $\bar{R}$ IMPROVEMENT VS COST OF ADDING CONSIGNMENT SPARES

- PROBABILITY OF SUFFICIENCY
- RELIABILITY GROWTH
- CONFIDENCE INTERVALS
- DESIGN TRADE STUDIES

COST OF TURNAROUND PENALTY VS ADDING A SEPARATE REPAIR FACILITY OR ADDITIONAL PERSONNEL

- QUEING ANALYSIS
- COST TRADEOFFS

SHIPMENT & PACKAGING

DOUBLE JEOPARDY

- LIQUIDATION DAMAGE (TAT)
- AVERAGE OPERATING TIME (AOT)

$3,000 (AOT) PENALTY FOR EACH DAY

TURNAROUND PENALTY

MOST SENSITIVE PENALTY

REFER TO GRAPH

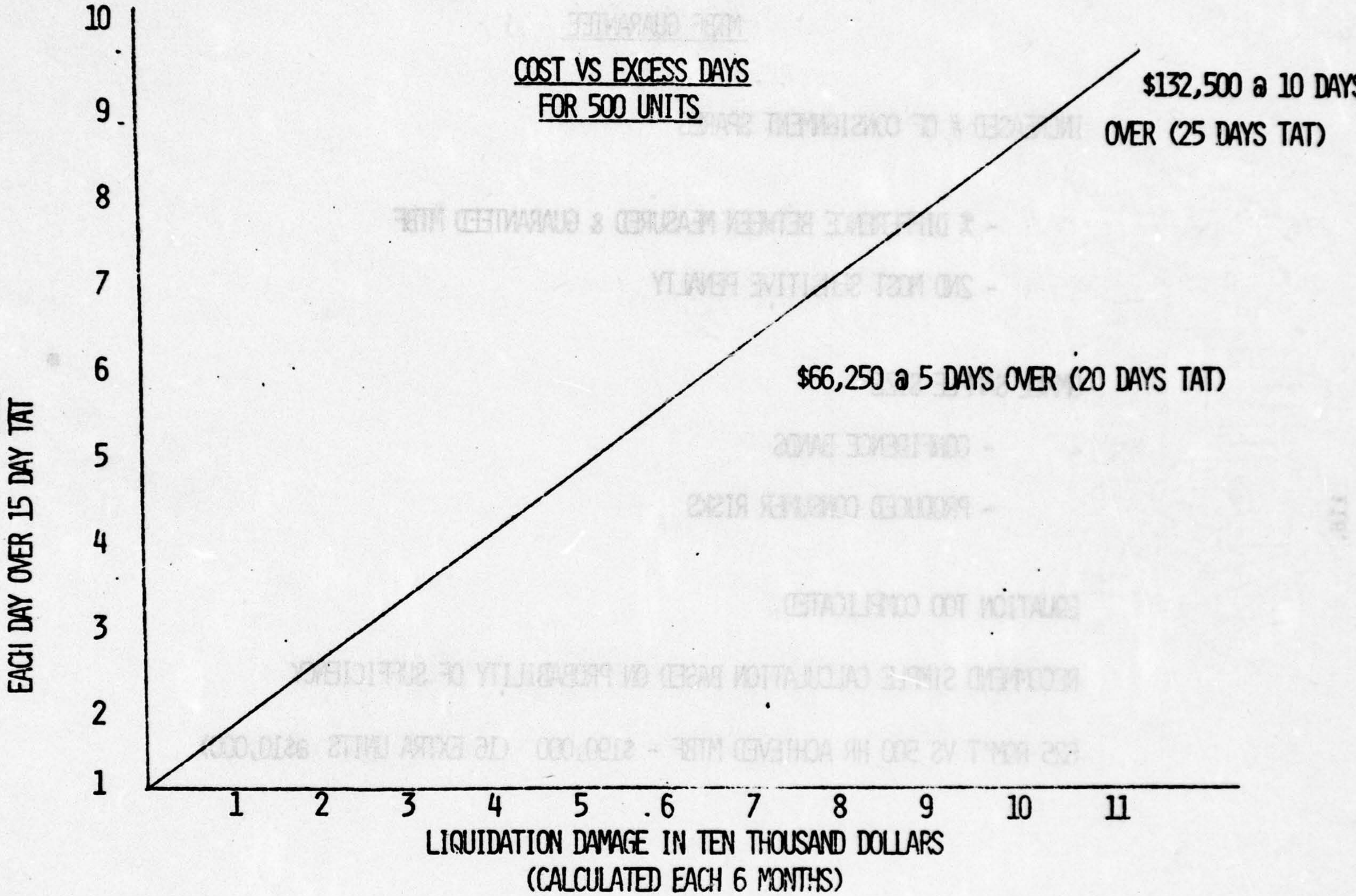
THE HIGHER THE QTY. OF OPERATIONAL UNITS THE MORE CRITICAL

PRODUCTION EMPHASIS

POSSIBLE QUEING IMPACT FROM LOWER MTBF'S EARLY IN PROGRAM

MANNING RQMT'S AND TURNAROUND (QUEING ANALYSIS)

SEPARATE REPAIR FACILITY TRADE STUDY



GRAPH NUMBER 1

MTBF GUARANTEE

INCREASED # OF CONSIGNMENT SPARES

- % DIFFERENCE BETWEEN MEASURED & GUARANTEED MTBF
- 2ND MOST SENSITIVE PENALTY

SMALL SAMPLE SIZE

- CONFIDENCE BANDS
- PRODUCED CONSUMER RISKS

EQUATION TOO COMPLICATED

RECOMMEND SIMPLE CALCULATION BASED ON PROBABILITY OF SUFFICIENCY

625 RQM'T VS 500 HR ACHIEVED MTBF - $190,000 (16 EXTRA UNITS @$10,000)

UNUSED WARRANTY

COST ALLOCATED TO EACH UNIT

REDUCTION IN OPERATIONAL QUANTITY WITH NO CHANGE IN AOT/UNIT

- # OF REPAIRS REDUCED (TOTAL COST OF REPAIRS IS ALSO REDUCED)
- WARRANTY COST REDUCED

REDUCTION IN OPERATIONAL QUANTITY WITH INCREASED AOT/UNIT

- # OF REPAIRS REMAINS AT SAME LEVEL
- INCREASED AOT (COST INCREASE) OFFSET BY UNUSED WARRANTY COST REBATE

REDUCTION IN NON-OPERATIONAL UNITS

- # OF REPAIRS REMAINS AT SAME LEVEL
- NO COST INCREASE FOR AOT
- WARRANTY REDUCTION NOT JUSTIFIED NOR OFFSET

WARRANTY RATE REQUIREMENTS

CONTRACTOR RECORDS OF RETURNED UNITS

- 10 ELEMENTS
- 3 REQUIRE ANALYSIS

LISTING OF UNITS IN SECURE STORAGE

UNIT REPAIR CYCLE TIME REPORT (RATES)

- 4 DATES

RELIABILITY REPORTS

- 4 ELEMENTS

WARRANTY POPULATION REPORT

- TIME REMAINING PER UNIT

CONTRACT PRICE ADJUSTMENT

- 5 ELEMENTS
- 3 REQUIRE ANALYSIS

ANNUAL WARRANTY EFFECTIVENESS REPORT

DATA COLLECTION ANALYSIS & REPORTING PLAN

SUMMARY OF PROBLEMS

TAT HIGH RISKS

MTBF HIGH RISK

INFLATIONARY FACTORS

LEGAL TERMS/CONDITIONS

COMPLICATED & UNJUSTIFIED FORMULAES

LARGE AMOUNT OF PAPERWORK

RECOMMENDATIONS

KISS

CONSIDER ALL VARIABLES IN COST PROPOSAL

UNDERSTAND/CLARIFY ALL CONDITIONS & CLAUSES

DON'T UNDERESTIMATE REPORTING REQUIREMENTS

Jim Taylor is employed by Honeywell Aerospace Division where his principal concerns are related to contract documentation requirements.

He has been an active member of the LCC Working Group of the JSDE/IS since its inception and has held various district and regional offices in the Society of Logistics Engineers.

COST/TIME FACTORS

FOR USE IN

LIFE CYCLE COST STUDIES

BY

James H. Taylor
HONEYWELL AEROSPACE DIVISION.
St. Petersburg, Florida

One of the major objectives of the Life Cycle Cost Task Group of the Joint Services Data Exchange for Inertial Systems is to develop sufficient historical cost/time standards data to permit use of standard values as an alternative in the performance of LCC Studies when standards are not provided by the procuring activity. The model provides a means whereby these standard or constants can be overriden by the user, the override feature can be used in special cases where it is known that actual costs would be significantly higher (or lower) than those provided in the model. Perhaps more importantly, the override feature can be used to test the sensitivity of the costs of a particular system to wide variation in these "standard costs".

The model is structured in three major categories; the RDT&E phase, the Acquisition phase, and the Operations and Maintenance phase as shown in Viewgraph #2. When deemed appropriate, the descriptions of equations are provided to the extent necessary only to identify areas where cost/time standards may be used. For precise definitions of each of the terms the user is urged to read the equations and their description in the Users Manual so that, in making his estimates, he does not overlook factors which should be included.

- LCC MODEL DESCRIPTION -

MODEL IS DIVIDED INTO THREE MAJOR CATEGORIES:

- RDT&E PHASE
- ACQUISITION PHASE
- OPERATIONS & MAINTENANCE PHASE

The next Viewgraph shows the RDT&E Technical Data equation, the elements underlined indicate where standard data may be used.

RDT&E SUB MODEL

The summary equation for RDT&E costs is:

$$R = CS + DE + TSR + TDR + SWR + TNR = ECP + RPM$$

$$TSR = TSH + TSS + TSER$$

$$TNR = TNER + TNP$$

$$RPM = RPMC + RPMG$$

Where: R = Total Cost of RDT&E

CS = Cost of Conceptual Studies

DE = Design of Engineering Cost

TSR = Cost of Testing

TDR = Cost of Technical Publications During RDT&E

SWR = Software Cost

TNR = Cost of Training During RDT&E

ECP = Cost of Engineering Change Proposal

RPM = Program Management Cost

TSH = Cost of Test Hardware

TSS = Cost of Test Spares

TSER = Cost of Test AGE/GSE/TE

TNER = Cost of Training Devices

TNP = Personnel Cost Associated with Training During RDT&E

RPMC = Contractor Program Management Cost per month X number of months

RPMG = Government Program Management Cost per month X number of months

THE COST OF TECHNICAL PUBLICATIONS DURING DEVELOPMENT

It is assumed that the engineering effort required for technical publications has occurred prior to this point and that these costs are related only to an average per page cost of writing and editing multiplied by the number of pages (including drawings) in the documentation. It should be apparent that the number of pages will be some function of complexity of the equipment. Consideration should be given to the fact that Technical Orders/Manual procured during the RDT&E Phase are usually engineering oriented and as such are usually much less complex than "Specification Type" manuals. Drawings may or may not be specification drawings. Thus, the specified requirement for drawings should be closely checked prior to using any standard.

- RDT&E TECHNICAL DATA -

TDR = (CTDO (TDP) + (CD) (TDD)

WHERE:

TDR	=	Cost of Technical Publications During Development
CTD	=	Average Cost per Page of Tech Data
TDP	=	Number of Technical Data Pages
CD	=	Average Cost per Page of Drawings
TDD	=	Number of Pages of Drawings

Recommended Cost Standards:

RDT&E Type Technical Manuals	160/page
CDRL (DD Form 1423) Type Data	120/page

PERSONNEL TRAINING COSTS

This equation covers the costs of both instructors and trainees during the training period. Instructor costs are assumed to be fixed regardless of the amount of actual instruction provided.

The next two Viewgraphs show where cost standards/constants may be used.

- RDT&E PERSONNEL TRAINING COSTS -

TNP + (MCM) (LTP) + (GTNH + TNCH) (MHG)

WHERE:

TNP = Personnel Cost Associated with Training

MCM = Manpower Cost per Month (INSTRUCTORS)

LTP = Length of Test Program in Months

GTNH = Ground Training Hours with Prime Equipment

TNCH = Test Equipment Training Hours

MHG = Personnel Cost per Training Hour

RDT&E TRAINING COST STANDARDS

MCM = Manpower Cost Per month (Instructors) a cost standard of $200 per classroom training hour is recommended. Includes training prep time, handouts, course outlines, etc.

MHG = Personnel Cost Per Training Hour. Recommend that same labor rates be used that apply to the technicians attending, i.e., $15/org., $15/Int., and $30/Depot (Cost per hour).

Should include per diem and transportation cost per student.

ACQUISITION COSTS

The acquisition cost category of the model is intended to define the initial investment costs to the user. Care must be exercised in applying the equations and assigning values to the various cost elements to be certain that costs are not duplicated in the RDT&E or O&M sections.

The costs computed in this phase are intended to be the cost of procuring the system being analyzed, plus the cost of those items (spares, support equipment, documentation, etc.), necessary for the user to make the system operational. The sum of all of these investment costs defines the total acquisition or investment costs, as defined in the following Viewgraph. The underlined elements of the equation indicate the areas where cost/time standards may be used.

ACQUISITION COST EQUATION

$$A = TTEA + SRAC + CINST + CSU + TSEA + TDA + SPHA + TNA$$
$$CFE + FACA + IMA + RIM^{*}$$

WHERE:

A	=	Total Acquisition Costs
TTEA	=	Production Tooling and Test Equipment Costs
SRAC	=	System Recurring Acquisition Costs
CINST	=	Equipment Installation Costs
CSU	=	Production Program Start-Up Costs
TSEA	=	Support Equipment Acquisition Costs (AGE, GSE, TE)
TDA	=	Technical Data Costs
TNEA	=	Training Equipment Costs
SPHA	=	Spares costs, including O&M Parts and Material
TNA	=	Initial Training Course Costs
CFE	=	Acquisition Field Engineering Costs
FACA	=	New Facility Costs
IMA	=	Initial Item Management Costs
*RIM	=	Recurring Item Management Cost

* NOT INCLUDED IN THE MODEL WHEN THIS PAPER WAS PREPARED (will be included at a later date).

TECHNICAL DATA COSTS

The technical data costs are shown in the next Viewgraph. It should be noted that specification type technical orders/manuals will be procured during the acquisition phase. Thus the development cost per page will be higher. The underlined elements will be discussed in detail.

Reference NTOD. Note: Non Technical order/manual type data required during the acquisition phase is always listed on the Contract Data Requirements List, (CDRL DD Form 1423).

Twenty five percent (25%) of the technical order/manual cost does not seem to be a valid assumption. As an example a contract might specify a manual which would equate to 350 pages, whereas the production quantities might equate to several years requiring status reports, test reports, etc., on a monthly basis which would result in a cost which would far exceed the manual cost or visa versa.

TECHNICAL DATA COSTS EQUATION

TDA + CP (TDV + TDG) + TDIC (TDV + TDG) + NTOD

WHERE:

CP = Cost per page = $160(Ref: 800-4)

TDV = Number of pages of AVE T.O.'s/Manuals

TDG = Number of pages of AGE T.O.'s/Manuals

TDIC = One-time Cost to Introduce a T.O. into Inventory = $4.00 per page (Ref: AFLCM 66-18)

*NTOD = 25% [(CP(TDV + TDG)] = cost of non-T.O. type technical Data required.

COST STANDARDS:

AFSCM/AFLCM 800-4	RECOMMENDED
a. Single page organization - $160; (TD)	$250
b. Printing and distribution per page per 1,000 copies - $3.00	$ 26 per 1,000 pages

* COST STANDARD IS NOT RECOMMENDED.

SPARES COST

The next Viewgraph contains the basic/top level equation for spares cost development. We detailed equations are contained in the Users Manual.

Maintenance turnaround times for Field/Shore Based/Shipboard Shop and Depot are discussed for both CONUS and overseas.

SPARES COST EQUATION (SPHA)

SPHA = SLRU + SSRU + SCOND + SPARTS

WHERE:

SLRU	=	The cost of spare LRU's
SSRU	=	The cost of spare SRU's
SCOND	=	The cost of spare LRU's and SRU's that are discarded (condemned) upon failure.
SPARTS	=	The cost of the initial lay-in of spare M&O parts and material.

SPARES STANDARDS

- For detailed spares equations the following standards as applicable are recommended:

- Maintenance turnaround (pipeline) time, in months:

A. Intermediate Field/Shorebased/Shipboard Shop -

CONUS & OS 0.3 month (AFSCM/AFLCM 800-4 .33 months)

B. Depot:

CONUS - <u>Organic Repair</u>:

- Platform or other Major Assembly	2.0 Months
- Other LRU's	1.5 Months
- Electronic Modules	1.0 Months
- Gyro Assembly	2.0 Months
- Accelerometer	2.5 Months

<u>Contractor Repair</u>:

- Platform or other Major Assembly	2.0 Months
- Other LRU's	1.5 Months
- Electronic Modules	1.0 Months
- Gyro Assembly	2.0 Months
- Accelerometer	2.0 Months

Overseas - <u>Organic Repair</u>

- Platform or other Major Assemblies	3.0 Months
- Other LRU's	2.3 Months
- Electronic Modules	1.5 Months
- Gyro Assembly	3.0 Months
- Accelerometer	3.5 Months

<u>Contractor Repair</u>

- Platform or other Major Assemblies	3.0 Months
- Other LRU's	2.3 Months
- Electronic Modules	1.5 Months
- Gyro Assembly	3.0 Months
- Accelerometer	3.0 Months

INITIAL TRAINING COST

TNA = Ini Initial Training Course Costs

$$TNA = \sum_{k=1}^{3} TNA_k$$

WHERE:

TNA_k = Training costs for the initial training of personnel at the kth level of maintenance.

and:

$k = 1$ = Organizational Level
$k = 2$ = Intermediate Level
$k = 3$ = Depot Level

$$TNA_k = \left[(ICL_k)\ (LRI_k)\ (NI_k)\right] + \left[(NS_k)\ (LRS_k)\ (ICL_k)\ (NC_k)\right] + CP_k + CM_k$$

where, for the k^{th} level of maintenance:

ICL_k = Initial course length

LRI_k = Instructor labor rate

NI_k = Total number of instructors

NS_k = Number of students per course

LRS_k = Student labor rate

NC_k = Number of courses to be given

CP_k = Course preparation cost

CM_k = Course material cost

NOTE: Training costs computed herein are the initial training costs only, i.e., recurring training is not included.

INITIAL TRAINING COST STANDARDS

LRI = INSTRUCTOR LABOR RATE

Contractor Instructor -- Estimate provided by Contractor.

Military Instructor -- Labor Rate $15 per hour

Civil Service Instructor (Depot) -- Labor Rate $30 per hour.

LRS = STUDENT LABOR RATE*

Organizational Level -- Labor Rate $15 per hour

Intermediate Level -- Labor Rate $15 per hour

Depot Level (Civil Service) -- Labor Rate $30 per hour

* Same as maintenance labor rate for any given level attending course.

CP = COURSE PREPARATION COST

(Should include instructor preparation time (LRI)

NOTE: Per Diem and Transportation Cost should be included for students.

NEW FACILITIES COST

The cost item will be a listing of new facilities required to support the system under study for each maintenance level as applicable, the quantity per maintenance level, the total quantity by item, the total cost per item or facility, and the grand total cost for new facilities.

The cost standard recommended for new facilities is $75.00 per square foot for the total space standard shop space required other cost standards are included in the next Viewgraph.

NEW FACILITIES COST

FACA = New Facilities Cost

$$FACA = \sum_{i=1}^{n} \left[(CFACA_i) \quad (QFACA_i) \right]$$

WHERE:

$CFACA_i$ = The cost of the i^{th} new facility.

$QFACA_i$ = The quantity of the i^{th} new facility.

COST STANDARDS FOR NEW FACILITIES -

	INITIAL	MAINT. COST YR.
Standard Shop Space	\$75/sq.ft.	8/sq.ft./yr.
Clean Room Space	\$300/sq.ft.	15/sq.ft./yr.
Special Features (Transformer, Tesmic Stand Screen Room, 400Hz Generator, Uninteruptable Power Source, etc.)	\$2400/each	\$100/year
Training Facility (classroom)	100/sq.ft.	10/sq.ft./yr.

INVENTORY MANAGEMENT

IMA = Initial Item Management Costs

IMA = IMCA (NPTA + NATA)

WHERE:

IMCA = The cost to introduce a new part type or new assembly type into the government inventory.

NPTA = The number of new part types to be introduced into inventory.

STANDARDS RECOMMENDED:

- Supply Management Cost New FSN Part $500/item
- Supply Management Cost New FSN Assy $1200/item
- Annual Supply Admin. Cost FSN Part $ 350/item/year
- Annual Supply Admin. Cost FSN Assy $ 750/item/year

The recurring costs for inventory management is not included in the model, but will be included at a later date.

OPERATION AND MAINTENANCE

The operations and maintenance (O&M) phase of the model is discussed in the next group of Viewgraphs. The total O&M cost is the summation of costs incurred at three levels of maintenance: Organization, Intermediate and Depot. It is assumed that there are only the three levels of maintenance, i.e., if two or more non-related activities perform the same maintenance function, the total cost for maintenance would be a weighted average.

Many of the O&M equations include a "k" factor. The "k" refers to a particular maintenance level being evaluated, i.e., k = 1 denotes the organizational level, k = 2 the intermediate level, and k = 3 the depot maintenance level. If an O&M function does not occur at a particular level, the equation(s) for that function should be "zeroed" out using the "override" procedures provided by the model.

O&M SUBMODEL

The summary equation for O&M cost is:

$$OM = \sum_{k=1}^{3} \sum_{t=1}^{n} OM_{kt}$$

WHERE: OM = Total Operation and Maintenance Cost

OM_{kt} = Operation and Maintenance Cost at k^{th} Level of Maintenance in Year t.

$k = 1$ = Organization Level

$k = 2$ = Intermediate Level

$k = 3$ = Depot Level

O&M SUMMARY EQUATION

The summary equation for O&M costs at the k^{th} level of maintenance in year t is:

$$OM_{kt} = NRS_k \sum_{i=1}^{n} (WC_{kti} + DL_{kti} + DM_{kti} + OL_{kti} + GA_{kti} + T_{kti} + RS_{kti})$$

Where: NRS_k = Number of Stations at the kth level of maintenance(level)

WC_{kti} = Warranty Cost in t^{th} Year for i^{th} Item at $k = 3$ level

DL_{kti} = Direct Labor Cost in t^{th} Year for i^{th} Item at k^{th} level

DM_{kti} = Direct Material Cost in t^{th} Year for i^{th} Item at k^{th} level

OL_{kti} = Overhead Labor Cost in t^{th} Year for i^{th} Item at k^{th} level

GA_{kti} = General Administrative Cost in t^{th} Year for i^{th} Item at k^{th} level

T_{kti} = Transportation Cost in t^{th} Year for i^{th} Item at $k = 2, 3$ level

RS_{kti} = Replenishment Spares in t^{th} Year for i^{th} Item at $k - 2, 3$ level

$k = 1$ = Organization Level

$k = 2$ = Intermediate Level

$k = 3$ = Depot Level

DIRECT LABOR RATE STANDARDS

DL = DIRECT LABOR COST

$$DL_{kti} = 12(TRKR_{kti}) \Big[(RTOK_{ki})\,(PLV_k)\,(MTTR_{ki})$$

$$+ (1-RTOK_{ki})\quad(MTTR_{ki}) \Big] \quad (DLR)$$

WHERE:

DL_{kti} = Direct Labor Cost in t^{th} Year for i^{th} Item at the k^{th} ML

$RTKR_{kti}$ = Number of Returns per Month to the k^{th} ML in the t^{th} Year for i^{th} Item

$RTOK_{ki}$ = Retest OK Rate at k = 2, 3 ML for i^{th} Item

PLV_k = Percent Labor Verification at k^{th} ML

$MTTR_{ki}$ = Mean Time To Repair at the k^{th} ML

DLR_k = Direct Labor Rate at the k^{th} ML

MAINTENANCE LEVELS (ML)

k = 1 = Organization
k = 2 = Intermediate
k = 3 = Depot

The recommended direct labor rate standards are as follows:

Organizational Level -----------$15/hour

Intermediate Level -------------$15/hour

Depot Level --------------------$30/hour

TRANSPORTATION COST EQUATION

T = TRANSPORTATION COST

$$T_{kti} = (12)\,(RTKR_{kti})\,(NRTS)\left[POI)\,(SCO)\,(W_i) + (1-POI)\,(SCC)\,(W_i)\right]$$

WHERE: T_{kti} = Transportation Cost at k^{th} ML in t^{th} Year for i^{th} Item

$RTKR_{ki}$ = Number of Returns per Month to the k^{th} ML in t^{th} Year for i^{th} Item

$NRTS_{ki}$ = Not Repairable Rate at k^{th} ML for i^{th} Item

POM = Percent Overseas Maintenance Stations

SCO = Shipping Cost Overseas

SCC = Shipping Cost CONUS

W_i = Weight of i^{th} Item

MAINTENANCE LEVELS (ML)

k = 1 = Organization
k = 2 = Intermediate
k = 3 = Depot

NOTE: Organizational maintenance level does not incur transportation costs normally.

TRANSPORTATION COST STANDARDS

	AFSCM/AFSCM 800-4	RECOMMENDED
1. Standard Preparation for Shipping Labor-Wage Rate:		
a. CONUS	$.1868	$1.25/pound(ship wt
b. OS	$.2331	$1.50/pound(ship wt
2. Standard Preparation for Shipping Material Rate:		
a. CONUS	$.0497	$2.00/pound(ship wt
b. OS	$.0620	$3.00/pound(ship wt
3. Ratio of Packaged Item Weight to Unpackaged Item Weight:		
a. CONUS	1.285	2.0
b. OS	2.436	2.5
4. Standard Shipping Rates (One Way):		
a. CONUS base to SRA or vice versa		
(1) Via Air	$.0895/lb.	$1.00/lb
(2) Via Surface	$.0294/lb.	$ .50/lb
b. OS base to SRA or vice versa		
(1) Via Air	$.3309/lb.	$2.00/lb
(2) Via Surface	$.0759/lb.	$1.00/lb

- JOINT SERVICE DATA EXCHANGE LCC CONSTANTS -

CONSTANT	DEFINITION	PHASE USED	DECIDE SERIES/ SEQUENCE #	USERS MANUAL PAGE NUMBER
CTD	Avg. Cost/page of Tech Data	RDT&E	4Ø4/424	3-8/4-15
CD	Avg. Cost/page of Drawings	RDT&E	4Ø4/424	3-8/4-15
MHG	Personnel Cost per Training Hour	RDT&E	4Ø6/426	3-9/4-17
CP	Cost per page of Tech Data	ACQ.	5Ø9/529	3-19/4-25
TDIC	One time cost to introduce a T. O. into inventory	ACQ	5Ø9/529	3-19/4-25
DTAT	Depot turnaround time in months	ACQ	517/527	3-21/4-24
ITAT	Intermediate Level turnaround time, in months	ACQ	517/527	3-21/4-24
LRS	Student Labor Rate	ACQ.	5Ø2/522	3-25/4-20
IMCA	Cost to introduce a new part type or new assy. type into Government inventory.	ACQ	5Ø6/526	3-26/4-23
(N.I.)*	Recurring inventory item management costs.	O&M	6Ø4/624	4-28
(N.I.)*	Technical Data Management	O&M	6Ø5/625	4-28
DLR	Direct Labor Rate	O&M	631/632/633	3-29/4-26
OLR	Overhead Labor Rate	O&M	631/632/633	3-32/4-26
GAR	General Administrative Rate	O&M	631/632/633	3-33/4-26
SCO	Shipping Cost Overseas	O&M		3-33
SCC	Shipping Cost CONUS	O&M		3-33

* NOT IDENTIFIED IN O&M ALGORITHMS

- RECOMMENDED STANDARDS/CONSTANTS SUMMARY -

CONSTANT	DEFINITION	RECOMMENDED
CTD	Avg. Cost/Page of Tech Data	R&D Type Manuals $160/page CDRL Data $120/page Specification Manual $250/page
CD	Avg. Cost/Page of Drawings	Per Drawing $800/drawing
MHG	Personnel Cost per Training Hour	Org.$15/hour, Int.$15/hour, Depot $30/hour
CP	Cost per page of Tech Data	Same as CTD
TDIC	One time cost to introduce a T.O. into inventory	$4.00/page Printing and Distribution $26/1000 pages
DTAT	Depot turnaround time in months	See page 16
ITAT	Intermediate Level turnaround time, in months	0.3 hours/month
LRS	Student Labor Rate	Same as labor rate for Maintenance Level
IMCA	Cost to introduce a new part type or new assy. type into Government inventory	Part $500/Item, Assembly $1200/Item
(N.I.)*	Recurring inventory item management costs.	Part $350/Item/Year - Assy $750/Item Year
(N.I.)*	Technical Data Management	None Recommended
DLR	Direct Labor Rate	Same as personnel training cost.
OLR	Overhead Labor Rate	Recommend Deletion
GAR	General Administrative Rate	Recommend Deletion
SCO	Shipping Cost Overseas	- See page -
SCC	Shipping Cost CONUS	- See page -

* NOT IDENTIFIED IN O&M ALGORITHMS

In summary, it is recommended that these constants/standards be delivered to the appropriate government authorities for review/publication; for use as alternative standards in the performance of LCC Studies.

John Willett is Naval Air Systems Command Representative, Pacific where his principal concerns are related to the costs of maintenance of aircraft engines.

He is a former Navy officer with many years experience in aircraft maintenance.

THE ASMRA PROGRAM

Presented by

John A. Willett

NAVAL AIR SYSTEMS COMMAND
REPRESENTATIVE, PACIFIC

The ASMRA Program (Adjustment of Scheduled Maintenance Requirements Through Analysis), was developed by the Naval Aviation Integrated Logistic Support Center, Patuxent River, Maryland under the direction of the Naval Air Systems Command Headquarters, Washington D.C.

The ASMRA Program today is made up of four major segments

- 200 Computer Analysis Programs
- Procedures/Documentation
- Central Data Base
- Computer Telecommunication Network

The ASMRA programs and its associated network was initially established as a tool for the Navy's Cognizant Field Activities (Naval Air Rework Facilities) maintenance engineers for use in the reestablishment of aircraft maintenance requirements. Basically changing from a calendar maintenance system to a phase flight hour maintenance system.

Currently the ASMRA program is a key tool in the further conversion to a reliability based maintenance system under the Analytical Maintenance Program. This program is using the Air Line Transport Association logic decision procedures to justify every scheduled maintenance requirement at the three levels of maintenance, Organizational, Intermediate and Depot. In addition, the ASMRA network is being used to store and analyze historical data to investigate the cause of fleet aircraft, and component problems affecting aircraft readiness and unacceptable maintenance workload. Naval Air Systems Command Headquarters is using the system to determine equipment failure and removal history,

maintenance actions, and related data to outline maintenance parameters for the new aircraft.

In creating the data file specification, the following were considered to be essential:

- Programs must measure parameters used to define problems.

- Relate specific equipments to the parameters measured for that equipment.

- Allow definition/identification of equipment from type/model/system to manufacture and part number levels.

- Capable of easily moving the focus of analysis from level to level i.e., system level to subsystem to part number.

The central data base as it exists today collects and stores data from maintenance action files, technical directive compliance, removal and installation files, equipment statistical data, repairable item data bank, the Naval Aviation Safety Center file, and unsatisfactory material reports. All Navy aircraft are contained within the file, maintaining a three year data file.

The computer network main data storage and processing is located in San Antonio, Texas, using an IBM 360/65. External users are six industrial facilities, Naval Air Systems Command, two Fleet Commanders and the Training Commands. Input data is received from fleet activities by the Fleet Maintenance Support Office Department, which processes the data and then forwards it to San Antonio. Naval Aviation Integrated Logistic Support Center is charged with the development and substaining maintenance of procedural programs.

The 10 major report programs are subdivided into over 200 hundred individual programs, ranging from flight data to maintenance history for system, sub-system, component and part number.

Three major objectives of the ASMRA program are to identify what equipment is effecting the effectiveness of the Naval Aviation Maintenance through:

- Equipment Conditional Analysis
- Schedule Removal Component
- Frequency of maintenance failure data

Additional uses are many, essentially to identify and isolate any problem area which impacts safety, maintenance or operational availability.

The main identifier is the use of the Work Unit Code, a seven digit numerical/alfa code assigned to every repairable item in a system or sub-system.,

Secondarily to the above, is the use of the Job Control Number which is used as the knot in tying together a specific Work Unit Code with the impact parameters resulting from a maintenance action.

Use of selection and sort procedures have been developed to better define and isolate the what, how, where, when, and why equipment causes problems. Selection and sort procedures allow the engineer to select almost any parameter required.

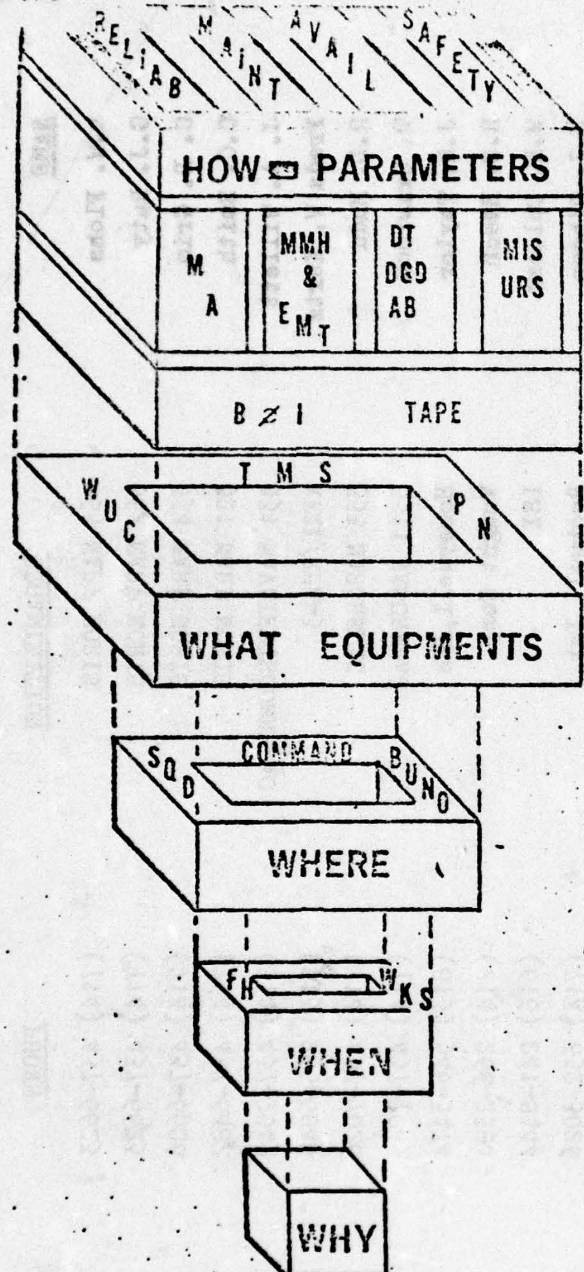
In summary the ASMRA

Provides the engineer with a tool to assist in the isolation and identification of equipment hindering the effectiveness of Navy aircraft.

- Enhance perspective by defining the magnitude of fleet problems in the areas of safety, availability and maintenance resources expenditures.
- Provides ready access to the maintenance history reported by the fleet, at any desired level or area of interest.
- Provides input into the Life Cycle Cost Program or Cost of Ownership as the case maybe, including Failure Free Warranty Programs.

The ASMRA System Today Is Made Up Of Four Major Segments:

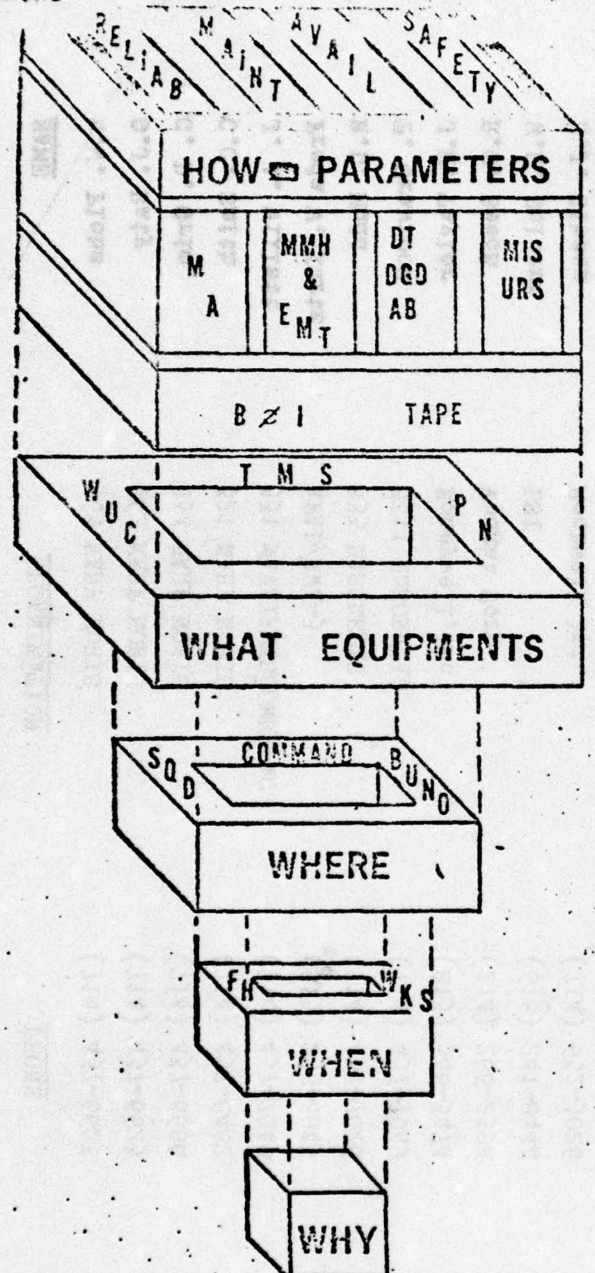
- 200 COMPUTER ANALYSIS PROGRAMS
- PROCEDURES/DOCUMENTATION
- CENTRAL DATA BASE
- COMPUTER TELECOMMUNICATION NETWORK



USE SELECTION /SORT FEATURES TO BETTER DEFINE AND ISOLATE:

- WHAT?
- HOW?
- WHERE?
- WHEN?
- WHY?

EQUIPMENTS ARE PROBLEMS



USE SELECTION /SORT FEATURES
TO BETTER DEFINE AND ISOLATE:

- WHAT?
- HOW?
- WHERE?
- WHEN?
- WHY?

EQUIPMENTS

ARE

PROBLEMS

4. LIST OF ATTENDEES

NAME	ORGANIZATION	PHONE
?.W. Flohs	363 NARF NORIS	(714) 437-6623
G.J. Raty	362 NARF NORIS	(714) 437-6623
C. D. Grim	334 NARF NORIS	(714) 437-6686
C.C. Smith	321 NARF NORIS	(714) 437-6482
J. A. Willett	331 NAVAIRSYSCOMREPAC	(714) 437-7049
Freda W. Kurtz	AFAL/RWA-3	(513) 255-6843
R.L. Mudd	333 NASCREPAC	(714) 437-7026
T. Grawrock	3311 NASCREPAC	(714) 437-7049
J.H. Taylor	Honeywell,INc	(813) 546-3474
R.C. Beech	Vought Corp.	(214) 266-2394
W.H. Colcord	LSI	(616) 241-8444
K.J. Gibson	Rochwell Int.	(714) 632-3026
W.Q. Wagner	Teledyne CAE	(419) 470-3041
T.E. Crosier	AGMC (XRX)	Autovon 580-7801
J.W. Mc Caw	323 NARF NORIS	(714) 437-6661
Capt. Dwight Collins	ASD/ACL, WPAFB	(513) 255-6836
Al Kumm	Delco Electronics	(805) 961-5117
Carl Gruetzmacher	Delco Electronics	(805) 961-5300
John Cianciarulo	DCAS	(714) 277-8900 x1654
Al Taschner	NARF 334	(714) 437-6686
R.E. Adel	Northrop	(213) 757-5181
R.B. Stauffer	J & R Associates	(603) 383-6883
Bill Laird	NARF 334	(714) 437-6686
Bob McGinnis	Rockwell Int.	(714) 637-3796